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# Storm Induced Beach Profile Changes along the Coast of Treasure Island, West-Central Florida, U.S.A.

Zhaoxu Zhu

*University of South Florida, [zhaoxuzhu@mail.usf.edu](mailto:zhaoxuzhu@mail.usf.edu)*

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**Storm Induced Beach Profile Changes along the Coast of Treasure Island, West-Central  
Florida, U.S.A.**

by

Zhaoxu Zhu

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Science  
School of Geosciences  
College of Arts and Sciences  
University of South Florida

Major Professor: Ping Wang, Ph.D.  
Ruiliang Pu, Ph.D  
Elizabeth Walton, Ph.D.  
Jun Cheng, Ph.D.

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Keywords: beach erosion, storms, nearshore sediment transport, beach profile changes.

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## **DEDICATION**

This is dedicated to my supportive friends and family.

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## **ABSTRACT**

Storms play a significant role in beach morphodynamics. Storm-induced beach-profile changes and their longshore variations are investigated in this study. The impacts of four summer tropical storms and two series of winter storms over the last 10 years along the coast of Treasure Island were documented. Tropical storms Alberto in 2006, Fay in 2008, Debby in 2012, Hermine in 2016 and winter storms in winter seasons of 2014 and 2015 are discussed in this study. In general, the Treasure Island beach experienced more erosion generated by tropical storms with greater intensity, but shorter duration, as compared to winter storms due to lower waves, weaker wind and smaller storm surge. Winter storms typically do not generate high storm surge and generally do not cause erosion at the dune and back beach unless the pre-storm beach is very narrow. Based on pre- and post-storm beach-profile surveys along the coast of Treasure Island, the northern end of the barrier island, located directly downdrift of the John's Pass tidal inlet, experienced erosion along the entire profile during the storms. Along the middle part of Treasure Island, dry beach suffered erosion during both the tropical storms and winter seasons while the nearshore zone suffered erosion during the tropical storms and experienced deposition during the winter seasons. Sunset Beach at the southern end experienced severe erosion during tropical storm Debby, but not during other storms. Winter seasons caused relatively small changes to the morphology of Sunset Beach. Deposition happened in the nearshore zone along Sunset Beach during winter storms. Survey line R143 at the very south end of Treasure Island suffered erosion in tropical storm Alberto, Debby and Hermine. Beach profile changes induced by Tropical storm

Fay was different as compared to other tropical storms. Considerably less beach erosion occurred due to the large distance of the storm path from the study area.

Overall, Sunshine Beach, bounded by John's Pass inlet at northern end of Treasure Island, was influenced both by wave conditions and the tidal flows. Sediment transport was to the north along the coast of Sunshine Beach when wind direction was from south, e.g. during tropical storm Fay. However the northward sediment transport was blocked by the John's Pass jetty. Therefore, deposition occurred at Sunshine Beach during tropical storm Fay. When wind direction was from north (e.g. during tropical storms Alberto and during the winter seasons), southward sediment transport was generated. Erosion occurs during the northerly approaching storms. The morphodynamics of the middle section of Treasure Island are influenced by the sand supply at the attachment point of John's Pass ebb delta. Sunset Beach experienced various levels of erosion during the tropical storms not only because of the high wave, strong wind and high water level generated by storms, but also due to the higher waves associated with an offshore dredged pit.

## **CHAPTER 1: INTRODUCTION**

With nearly 66% of the world's population living in close proximity to a shoreline (Komar, 1998), and 50% of the U.S. population living within 80 km of the coast (NOAA, 2011), beaches and barrier islands as desirable coastal environments have a tremendous effect on the daily life of a large number of people. The current situation of the coasts in the U.S is that 86% of the U.S. eastern coasts are in retreat, and 90% of the U.S coastlines are going to be in retreat in the near future (Heinz, 2000). Beaches are one of the most important natural resources to Florida's economy and eco-systems (Houston, 2002). Millions of tourists come to Florida to enjoy their vacation with family and friends because of the beautiful beaches and 75% of summer travelers plan to visit beaches (Morgan, 2000). Beaches also provide an important habitat for numerous marine species (Yamamoto et al., 2012). However, beaches are extremely dynamic and are subject to erosion, especially during storm events (Elko and Wang, 2007; Roberts, 2013).

Erosion is defined as a gradual wearing away of the Earth's surface by the action of natural forces of wind and water (Liu et al., 2011). For a beach environment, erosion is caused by a negative sediment transport gradient. In other words, erosion occurs at a specific beach when more sand is transported away from the beach than moved to the beach. It is a process generally affected by large storms, flooding, strong wave action, sea level rise and human activities (Costal Erosion, 2016). According to NOAA 2013, over 324 km<sup>2</sup> of wetland were lost in U.S. every year between 2004 and 2009 due to erosion.

Field measurements suggest that beach-profile changes are characterized by substantial temporal and spatial variations (Larson and Kraus, 1994; Roberts and Wang, 2012; Brutsche et al., 2014). Spatial variations can be rapid in that two adjacent beaches and profiles may change differently. Temporal scales can be dynamic in that large changes can happen in a short time during storms, while during calm conditions little to no changes may occur for a long period of time. These temporal and spatial variations are controlled by numerous interactive factors including geologic, morphologic, sedimentologic, and hydrodynamic conditions (Roelvink et al., 2009; Walstra et al., 2012, Coco et al., 2013). The largely unpredictable nature of extreme storms makes it difficult to plan and execute pre-storm field data collection. This problem can be resolved by bimonthly to quarterly surveys of beach profiles. Thus, the existence of pre-storm data makes it possible to quantify the dramatic morphological impact of storms (Wang et al., 2006). Due to the energetic conditions in nearshore environments, long-term and field measurements of beach-profile changes along a significant stretch of coastline are limited to only a few locations. Examples include Duck Beach, North Carolina, USA (Holman and Sallenger, 1993), Egmond, Netherlands (Ruessink et al., 2000), Hasaki, Kashima Coast, Japan (Kuriyama, 2008), and Gold Coast, Australia (Castelle et al., 2007).

Beach morphodynamics at annual temporal and kilometer spatial scales within the barrier island coast are often significantly influenced by the interruption of longshore sediment transport by complex tidal-inlet processes (Roberts and Wang, 2012). Tidal inlets are gaps in the shoreline (often associated with barrier islands) where water flows through, connecting the ocean and back bays and/or lagoons (FitzGerald 1993). The morphology of tidal inlets typically contains ebb deltas and flood deltas (Hayes, 1980). Ebb deltas are usually developed seaward of the barrier island at the end of the main ebb channel of the tidal inlet and flood deltas typically are formed

landward (Brownell, 2013). The morphodynamics of barrier islands are generally controlled by the relative dominance of tide and wave forcing (Davis, 2013).

A sandbar is a common dynamic morphologic feature found along sandy beaches. It has substantial influence on patterns of wave breaking, and is therefore often referred to as a “breaker-point” bar. It reduces the incident wave energy arriving at the shoreline and therefore provides protection against beach erosion. Due to its control on wave breaking, sandbars influence the spatial distribution of turbulent kinetic energy generated by breaking waves as they propagate to the shore (Scott et al., 2005; Cheng and Wang, 2015). During storm conditions, offshore sandbar migration typically occurs as a result of strong undertows associated with intense wave breaking (Thornton et al. 1996). While under swell conditions, typical of a summer season, the deformed wave-orbital velocities cause the sandbar to migrate onshore (Hoefel and Elgar, 2003; Cheng et al., 2015).

This study focuses on effects of various storms on beach-profile changes. These storms are distinguished as tropical storms and winter storms based on the season in which they occur. In this study, “summer” is defined as the time period from the beginning of May to the end of October and “winter” is defined as the time from the beginning of November to the end of the following April. This distinction of seasons is also used in studies including Davis (2013) and Roberts and Wang (2012). Tropical storms can generate large waves, strong wind and high storm surge. Winter storms can generate high and long-lasting waves and strong wind, but typically without significant storm surge, which could have different influences on beach profiles.

Beach profiles, extending from the dune region to short term depth of closure, spaced at approximately 300 m, have been surveyed monthly to bi-monthly along the coast of west-central Florida by the University of South Florida (USF) Coastal Research Laboratory since the

completion of a beach nourishment project in 2006. So far the effects of a single storm on the beach along the coast of west-central Florida have been studied including, e.g. Tropical Storm Debby 2012 (Brutsche et al, 2014; Cheng and Wang, 2015), and Hurricane Ivan 2004 (Elko and Wang, 2007). However, comparison of the impacts by different storm events has not been conducted. This study compares and discusses the effects of long-shore variations of beach profile changes induced by several storms over the last decade along the coast of Treasure Island.

In this study, wave height, water level and wind speed are compared before the storms and during the storms in order to interpret beach profile changes. The objective of this study is to address beach profile changes in response to water level, storm surge and wave height changes cause by storms. The morphological changes induced by tropical storm and winter storms are discussed. The influence due to the two kinds of storms will be compared in this study.

This thesis is organized as follows. Chapter 1 provides a general overview and introduction of this study. Chapter 2 introduces the morphology and engineering history of study area, Treasure Island, Florida. Chapter 3 presents the methodology and data used in this study. Chapter 4 provides the results of this study and how beach profiles changed due to storm events and how one storm influenced one part of Treasure Island differently than others. Discussion of the results are also included in this chapter. Chapter 5 presents the conclusions for this study.

## CHAPTER 2: STUDY AREA

Treasure Island is a 4.1 km<sup>2</sup> barrier island located in Pinellas County, west-central Florida, facing the Gulf of Mexico. The study area has a mixed tidal regime with diurnal spring tide ranging from 0.8 to 1.2 m and semi-diurnal neap tide ranging from 0.4 to 0.5 m (Wang et al., 2015). An average nearshore wave height was measured at 0.25 to 0.30 m along the coast of Treasure Island (Wang and Beck, 2012). A net annual southward longshore sediment transport is driven by wind and waves induced by frequent winter cold fronts which come from a northerly direction (Wang and Beck, 2012). This barrier island can be generally divided into three sections alongshore, Sunshine Beach at the northern end, Middle Beach in the middle, and Sunset Beach at the southern end of the island (Figure 1).



**Figure 1.** Location of Treasure Island.

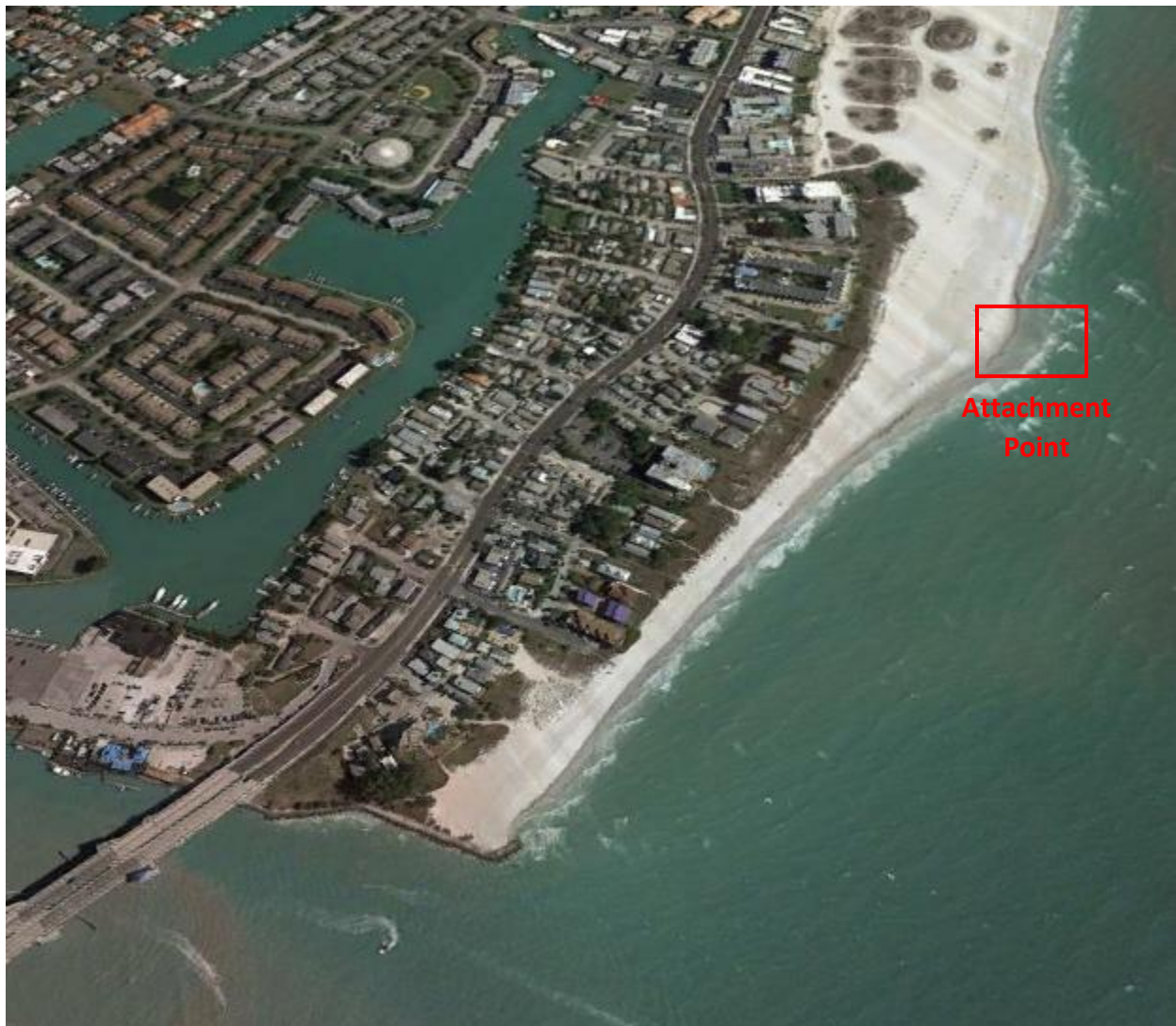


**Table 1.** List of highest recorded storm tides in west-central Florida prior to 1980 and storm tides refers to the maximum water level elevation measured by a water level station during storm events. The location of measurement is in parentheses (USACOE, 1984b).

Date	Event	Storm Tide Height (m)
September 25, 1848	Hurricane	4.6 (Tampa)
October 19, 1926	Hurricane of 1926	3.7 (Ft. Myers)
October 12, 1848	Hurricane	3.0 (Tampa)
October 24, 1921	Hurricane of 1921	2.9 (Tampa)
September 10, 1960	Hurricane Donna	2.4 (Ft. Myers)
September 4, 1950	Tropical Storm	1.7 (Tampa)
October 18, 1968	Hurricane Gladys	1.5 (Tampa)
June 18, 1972	Hurricane Agnes	1.5 (Tampa)

Sunshine Beach is bounded to the north by John's Pass Inlet. John's Pass was created by the Hurricane of 1848, which is recorded as the hurricane with the highest storm tide (4.6 m) on this coast (USACOE, 1984b; Table 1). The inlet subsequently grew in size and became the primary inlet serving northern Boca Ciega Bay by the 1920s (Barnard, 1998). John's Pass is a

mixed energy inlet with a flood-tidal delta that is stable with large percentage of vegetation cover (Barnard, 1998). As shown in Figure 1, the portion of Boca Ciega Bay, directly landward of John's Pass, is larger and not dissected by man-made islands and compared to the portion landward of Blind Pass (Wang et al., 2011). The large ebb-tidal delta is skewed to the south as controlled by the southward longshore sediment transport (Wang et al., 2011). The downdrift attachment point is located approximately 1 km south of the inlet (Figure 2).



**Figure 2.** John's Pass ebb-tidal shoal and attachment point.

Figure 3 illustrates a generalized pattern of net longshore sand transport along Treasure Island. The attachment point is considered as a divergent zone of longshore transport, which is induced by wave refraction over the John's Pass ebb shoal and flood tidal current along the beach (Wang et al., 2015). The sand supply from John's Pass ebb tidal shoal results in a wide beach at the attachment point. Along the Middle Beach at Treasure Island, net longshore sand transport is toward the south. However, along Sunset Beach, an increase in the rate of longshore transport occurs, likely due to the increased wave height landward of a dredged pit (Wang et al., 2015). Severe erosion occurs at this portion of the beach due to the negative gradient of longshore transport. The sand impoundment is apparent at the north jetty of Blind Pass.

Blind Pass is a wave-dominated inlet which has migrated 1.7 km to the south since John's Pass became the dominant inlet of this area (Barnard, 1998). As John's Pass gradually captured a substantial portion of the tidal prism, the net longshore sediment transport caused rapid southward migration of Blind Pass (Davis and Barnard, 2003), as illustrated by the long southward migrating spit. Jetties constructed in 1937 fixed the entrance channel into a 90-degree turn which eventually stabilized Blind Pass. The wide entrance channel relative to the small tidal prisms at Blind Pass has become an effective trap for the southward longshore transport (Wang and Beck, 2012). The federal government authorized the Pinellas County Beach Erosion Control Program in 1966. The U.S. Army Corps of Engineers published a General Design Memorandum (GDM) in 1968, which recommended the creation of a parallel shore borrow pit just offshore Sunset Beach to nourish eroded beach. Since then, a total number of 14 federal fill placement projects have been implemented at Treasure Island. Overall, the opening and evolution of John's Pass played a significant role in the morphology of Blind Pass.



**Figure 3.** Generalized trend of net longshore sand transport (LST) along Treasure Island.

## **CHAPTER 3: METHODOLOGY**

### **3.1 Field Methods and Data Analysis**

Over the last 10 years, beach profiles along the west-central Florida coast were surveyed bimonthly by USF Coastal Research Laboratory. Additional surveys were conducted pre- and post-storms to further capture storm induced beach changes. The field survey followed the traditional electronic level-and-transit survey procedure. This procedure typically requires three people, with one instrument person, one rod-person responsible for the land part of the survey, and one swimmer for the ocean part of the survey (Cheng et al., 2016). A Topcon total survey station and a 4-m survey rod with a prism attached to it were used for this procedure (Figure 4). In order to prevent the survey rod from sinking into the soft sand to ensure accuracy of the measurement, a flat footer was attached to the bottom of the survey rod instead of the typical pointy footer.

Global Positioning System-Real Time Kinematic (GPS-RTK) was used to acquire accurate locations of the instrument and benchmark prior to conducting each beach profile survey. This provided accurate elevation control for the entire survey line. For this study, the elevations are referenced to North American Vertical Datum of 1988 (NAVD88) in meters. NAVD88 zero is 8.2 cm above mean sea level (MSL) and the survey lines extend to roughly -3 m NAVD88 or short-term depth of closure (Wang and Davis., 1999). The instrument and benchmark are typically placed in the dune area far away from anthropogenic disturbance to avoid being removed by beach visitors. The instrument and benchmark points are usually established perpendicular to the shoreline in order to obtain a cross-shore beach profile (Cheng,



2016). Two orange cones (or two wood sticks with orange tape tied to the top of them) are typically used to set a visual survey line for the rod-person, which is much more efficient than directed by the instrument person.



**Figure 4.** Survey procedures include the use of an electronic level-and-transit total station and a 4-m survey rod.

There are a total of 17 beach profile survey lines at Treasure Island from R127 at the northern end of the island to R143 at the southern end (Figure 5). Most of the survey lines are approximately 300 m apart. During each survey, the elevation and location of the points where beach-morphology change occur were recorded by the Topcon total station. The rod person, who visually determines the locations of morphology change, plays a crucial role in the survey accuracy. Instead of taking survey points with uniform fixed space interval, which may miss crucial features such as scarps or bar crests, the rod-person decides the point location with the goal of capturing all important topographic changes. Typically, denser points are taken where slope changes occur (e.g. foreshore, berm crests, sandbar), and fewer points are taken where topography is uniform (e.g. flat back beach). This procedure allows efficient measurement of the beach-profile changes (Cheng et al., 2016). Distance (d) from benchmark to each survey point is calculated as shown by formula (1):

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

Where  $x_1$  is easting of the monument,  $x_2$  is the easting of individual survey point,  $y_1$  is the northing of the monument, and  $y_2$  is the northing of individual survey point (Davis, 2013). By plotting the elevation and distance from benchmark using Matlab or Microsoft Excel, a beach profile is obtained. Time-series beach changes can be obtained by comparing the beach profiles surveyed at different times (Figure 6, see page 14). The vertical axis represents the elevation referenced to NAVD88 in meters and the horizontal axis refers to the distance to each benchmark. As shown in Figure 6, the contour line retreated approximately 10 m at the elevation of 1 m after tropical storm Alberto. And a sand bar was generated offshore at the location approximately 220 m away from benchmark. Therefore, the beach changes can be recorded by profiles surveyed before and after the storm.

## 17 Survey Lines on Treasure Island



### Legend

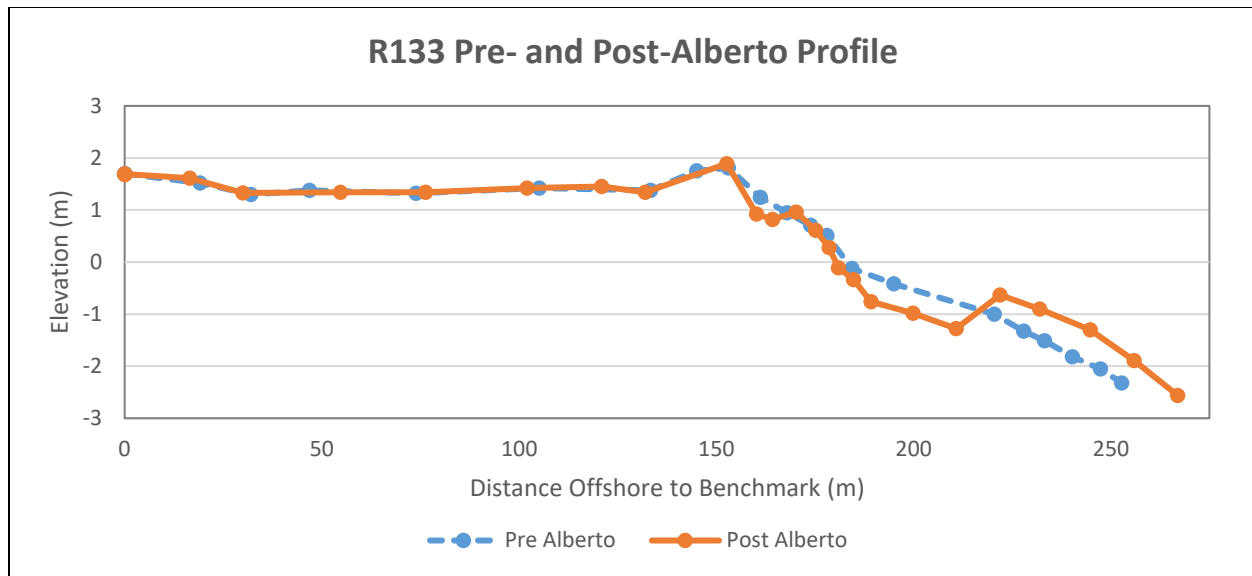
• Survey Points

0 .5 1  
Kilometers

Source: USF Coastal Research Lab  
Made by: Zhaoxu Zhu  
Date: 9/30/2016

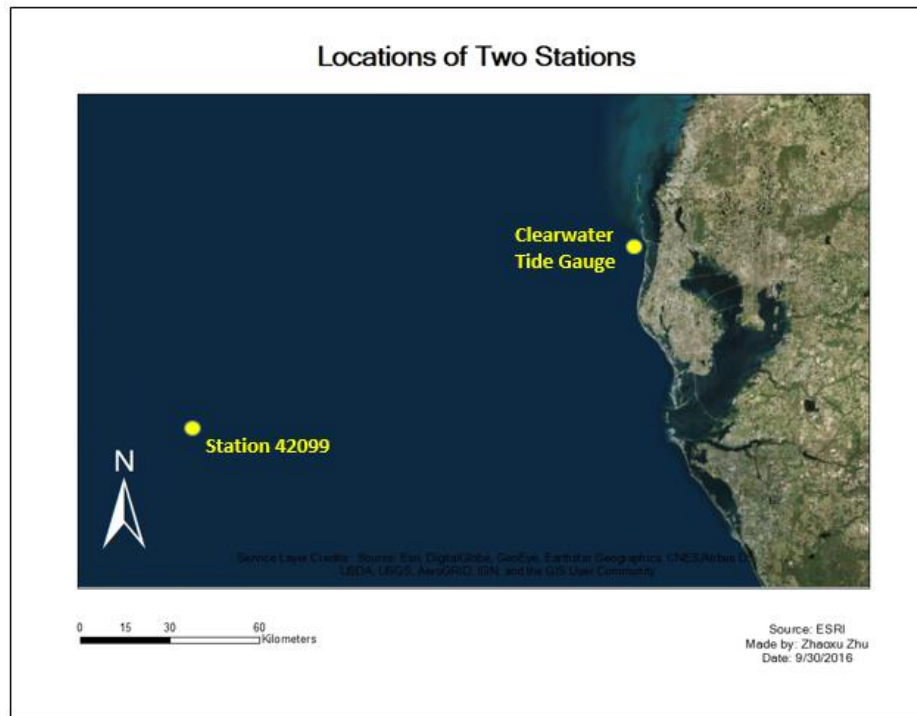
**Figure 5.** Seventeen profiles at Treasure Island from R127 at the north end to R143 at the south end.





**Figure 6.** An example of beach profile pre- and post-tropical storm Alberto, 2006.

Tropical storm and winter storm data are collected by the National Oceanic and Atmospheric Administration (NOAA) and are available at NOAA's National Data Buoy Center website ([www.ndbc.noaa.gov](http://www.ndbc.noaa.gov)). The wave conditions measured at 150 km offshore at Station 42099 and water level measured at NOAA Clearwater Beach Tide Station (CWBF1) approximately 20 km north of the study area are used here (Figure 7). The reason these two stations are used is that they have the longest and most continuous data in the greater study area. In this study, water level, wind speed/direction and wave conditions during tropical storms and one month before storms were downloaded from NOAA. The pre-storm data are considered as normal data in this study and they are used as reference to the storm data. Water level and wind speed/direction are compared to examine their differences, particularly during the passages of tropical storms. Wave condition is discussed by comparing the wave heights during tropical storms to pre-storm wave heights.



**Figure 7.** Locations of Clearwater water tide gauge and Station 42099.

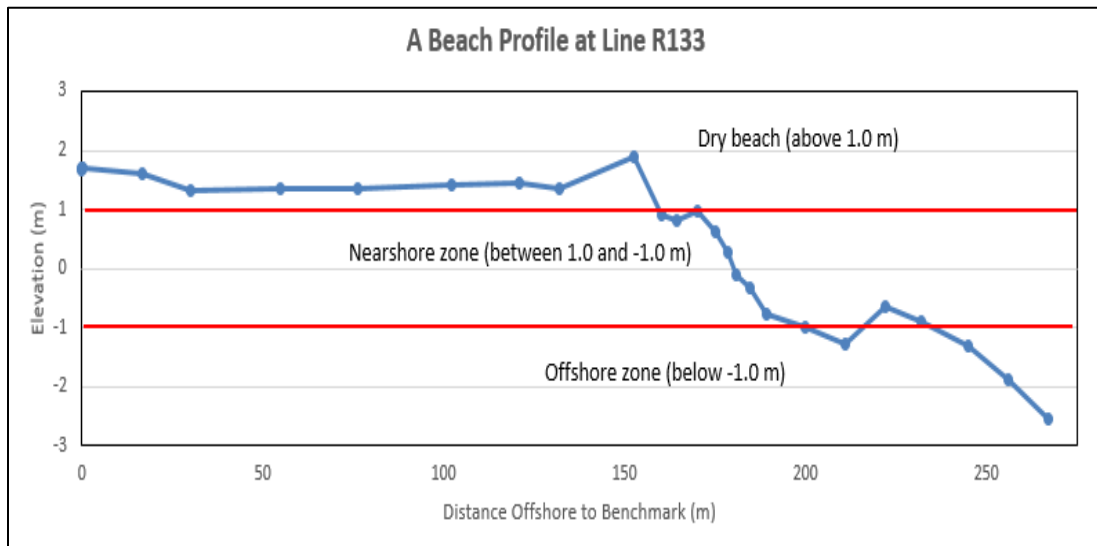
### 3.2 Storm Selection

Tropical storms are generally classified based on wind speed using the Saffir-Simpson classification. A storm with wind speeds less than 39 mph is classified as a tropical depression. Tropical storms have wind speeds between 39 mph and 73 mph. A storm with wind speed between 74 and 110 mph is classified as a hurricane. A storm with wind speed greater than 110 mph is defined as major hurricane. Beach changes caused by both tropical storms and winter storms were examined in this study. The four tropical storms studied here include tropical storm Alberto in mid-June of 2006, tropical storm Fay in late July of 2008, tropical storm Debby in late June of 2012 and the most recent tropical storm, Hermine, in late August 2016. Winter storms accompanying the passages of cold fronts occur much more frequently than tropical storms. Passages of winter cold fronts typically occur approximately every 10-14 days during the winter

months. Some of the frontal passages can generate energetic storms. And two of those winter storms are examined here, one from the winter of 2014 and one from the winter of 2015.

## CHAPTER 4: RESULTS AND DISCUSSION

The measured beach-profile changes along Treasure Island are linked with water level, wind speed and wave conditions measured before and during the storms. Pre-storm water level and wind speed were obtained from one month before each storm which represents the normal water level and wind speed conditions. The one-month duration was used because that typically represents the time period between the pre-storm survey and the actual storm event.



**Figure 8.** An example of beach profile at survey line R133 shows the contour levels. Dry beach is considered as the section above 1.0 m; the nearshore zone is considered the section between 1.0 and -1.0 m; and the offshore area is considered as the section below -1.0 m.

For the purpose of covering longshore variations of beach–profile change along the entire island, the profile changes at survey lines R127, R129, R133, R141 and R143 are discussed. For

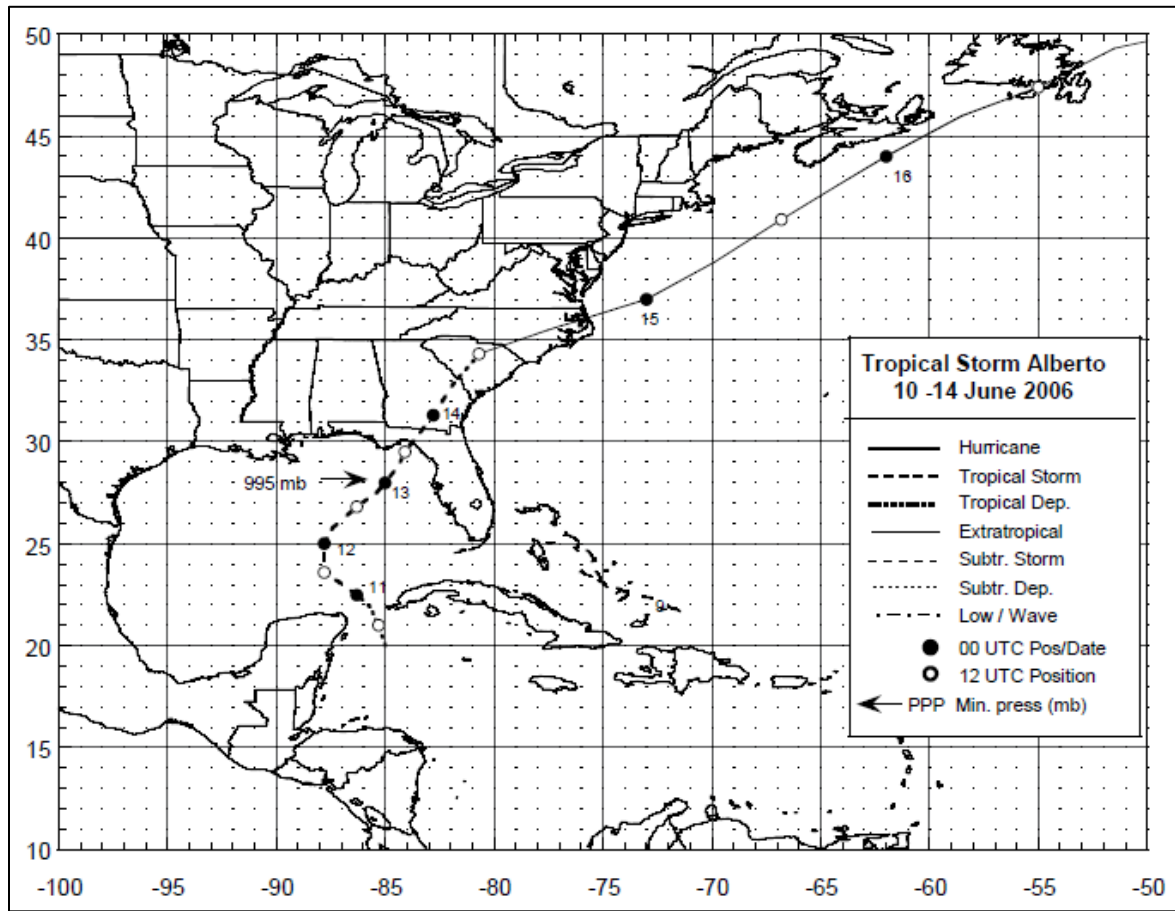
the convenience of discussion, the contour line changes at the elevation of 1.0 m, 0.0 m and -1.0 m referenced to NAVD88 are discussed (Figure 8). The beach above the elevation of 1.0 m is considered as the dry beach area; the area between the elevations from 1.0 to -1.0 m is considered as the nearshore area; and the area below the elevation of -1.0 m is considered to be the offshore zone.

#### 4.1 Beach Profile Changes Induced by Tropical Storm Alberto, 2006

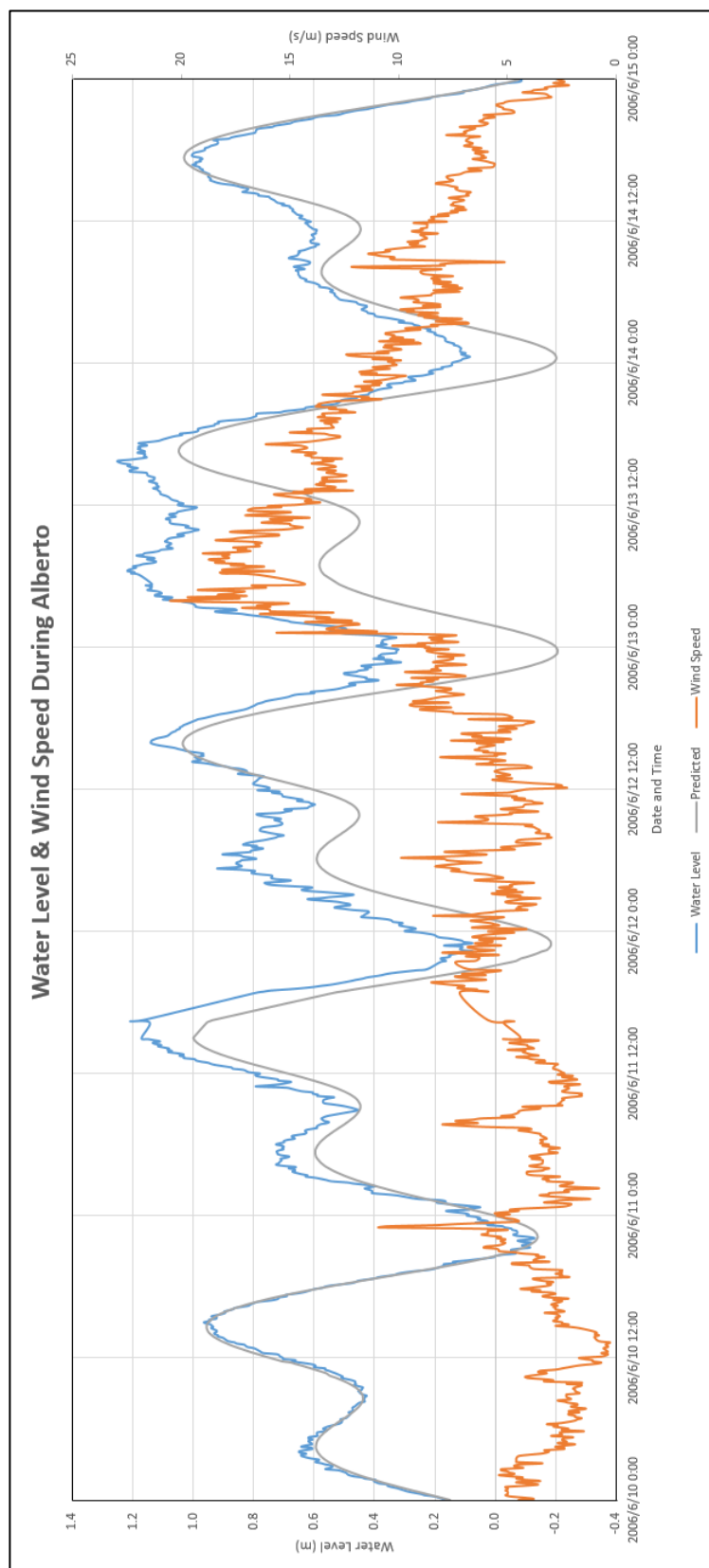
Tropical storm Alberto was first formed from a depression in the northwestern Caribbean on June 8, 2006. A circulation and organized convection were observed on June 10, which led to the classification of the system to be a tropical depression (Avila and Brow, 2006). The depression became a tropical storm by the effect of a region of a strong southwesterly wind shear on June 11 (NOAA). Then the storm started moving northeastward and made landfall near Adams Beach, Florida on June 13, 2006. Alberto continued moving northeastward inland and weakened. Figure 9 illustrates the track of Alberto as it made landfall on Adam Beach. Alberto caused severe flood damage and trees were downed at the landfall area. This tropical storm generated high waves and strong winds which caused erosion in the vicinity of the landfall and had a significant influence on the study area.

Tropical storm Alberto generated strong wind speeds with a mean speed of 7.11 m/s and a peak storm surge was 0.73 m. Wind conditions and water level are showed in Figure 10. The maximum wind speed during the storm reached 20.5 m/s. During the one month pre-storm period, the mean wind speed was 4.74 m/s and the peak surge was 0.18 m. Figure 11 illustrate the wind condition and water level before Alberto. Comparing these two sets of data, the mean wind speed increased 49.97% and the peak storm surge increased approximately 3 times. Pre-storm surge and wind speed are regarded as normal conditions. In this case, over that period time of pre-

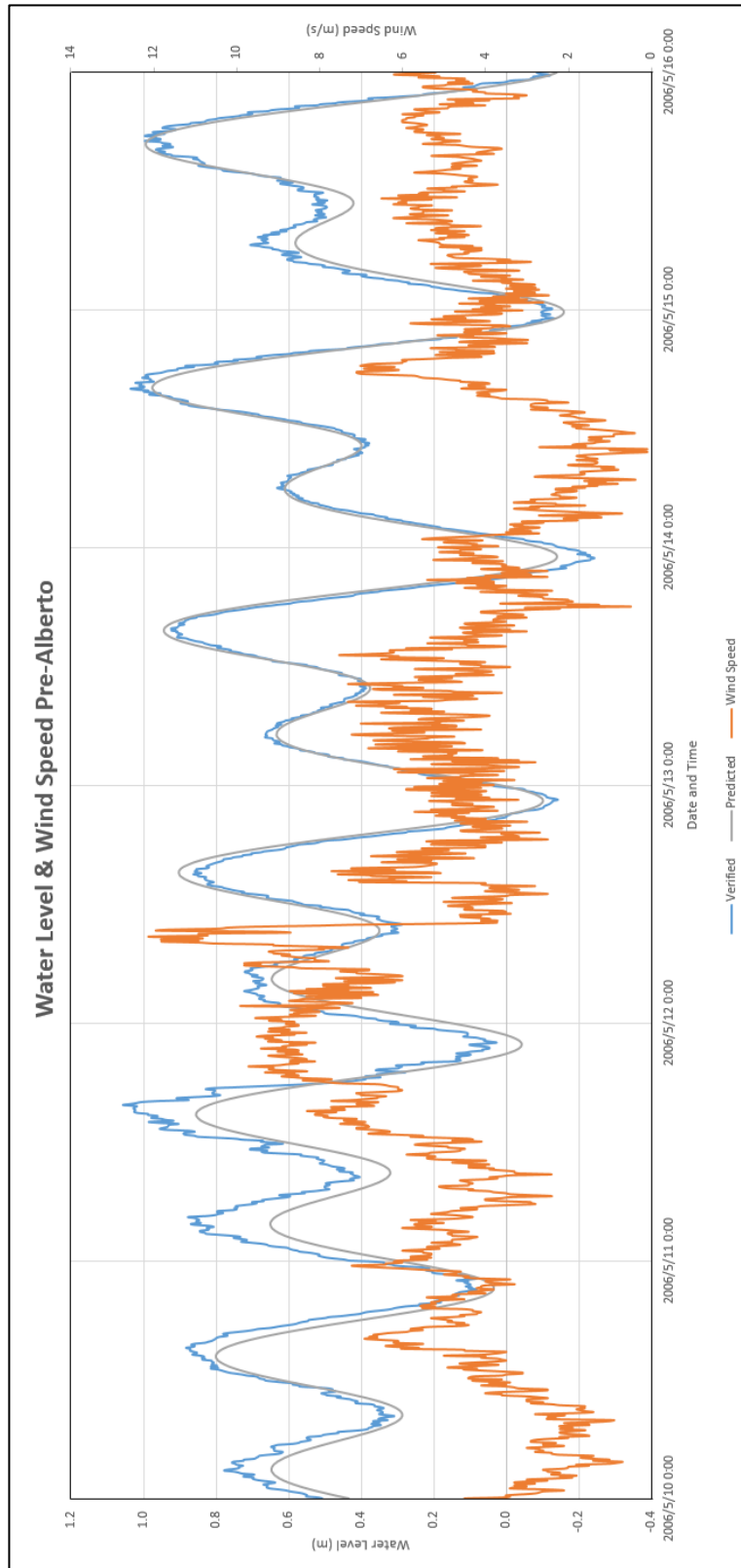
storm, measured water level could almost match the predicted water level. On May 11, wind speeds increased to around 6 m/s. Because of a significant wind speed increase between June 11 to 14, storm surge increased to a maximum value on June 13 at approximately 6:00 a.m.



**Figure 9.** Track positions for Tropical Storm Alberto, 10-14 June, 2006. Track during the extratropical stage is based on analyses from the NOAA Ocean Prediction Center and a post analysis performed at NHC (NOAA).



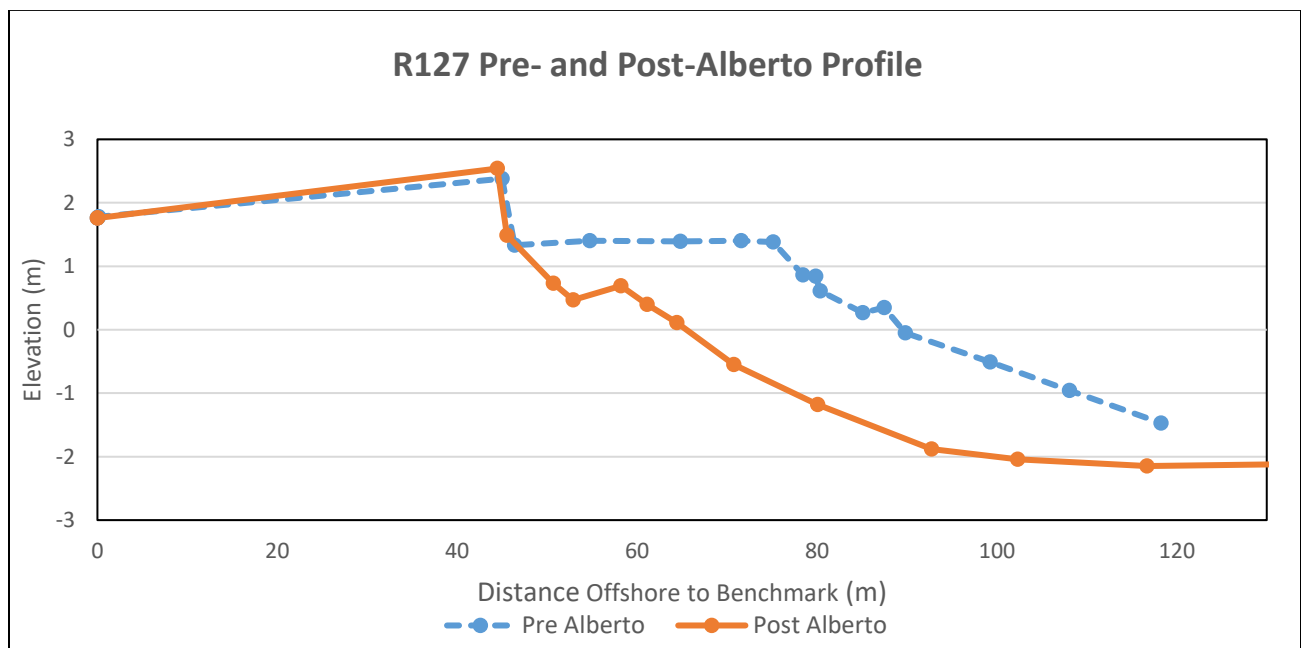
**Figure 10.** Water level and wind speed during tropical storm Alberto, 10-15 June, 2006.



**Figure 11.** Water level and wind speed pre- tropical storm Alberto, 10-15 May, 2006.



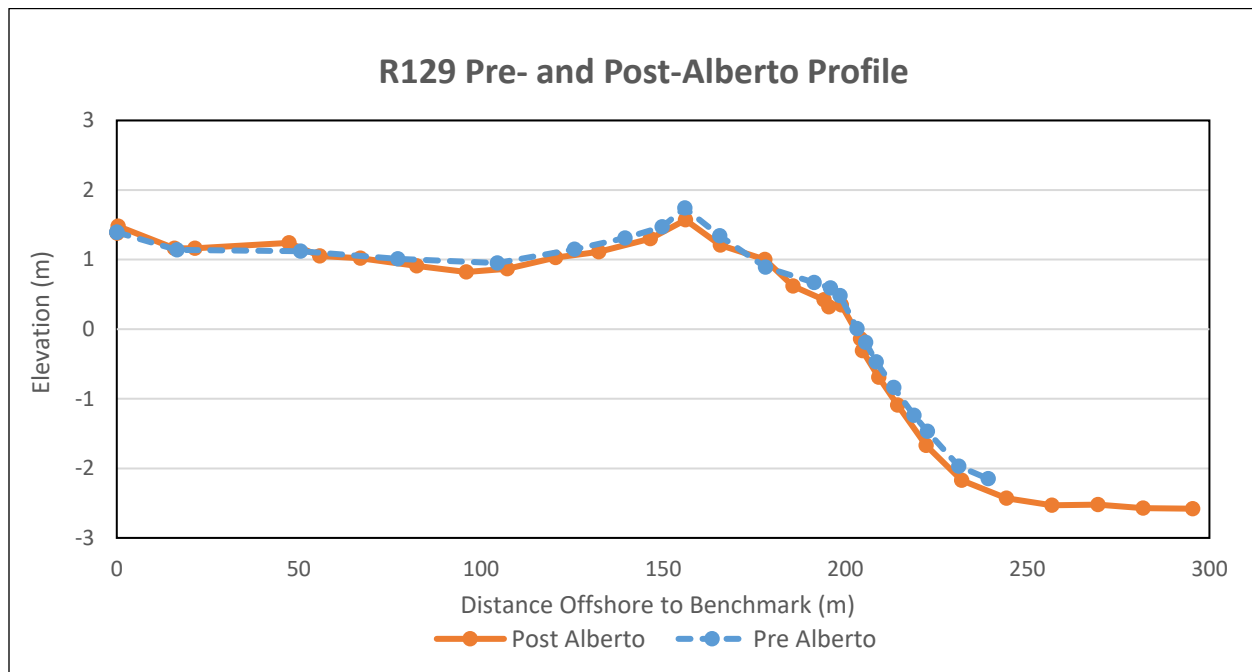
Profile R127 experienced erosion during the storm as shown in Figure 12. A comparison of beach profile R127 before and after tropical storm Alberto indicates that the contour line of dry beach retreated approximately 24 m landward at the elevation of 1.0 m; at the elevation of 0.0 m, the contour line moved approximately 24 m landward; and at the elevation of -1.0 m, the contour line moved approximately 24 m landward as well. These measurement indicate that the entire profile shifted landward. The measured sand loss was approximately 80 m<sup>3</sup>/m.



**Figure 12.** Beach profile changes at survey line R127 due to Alberto.

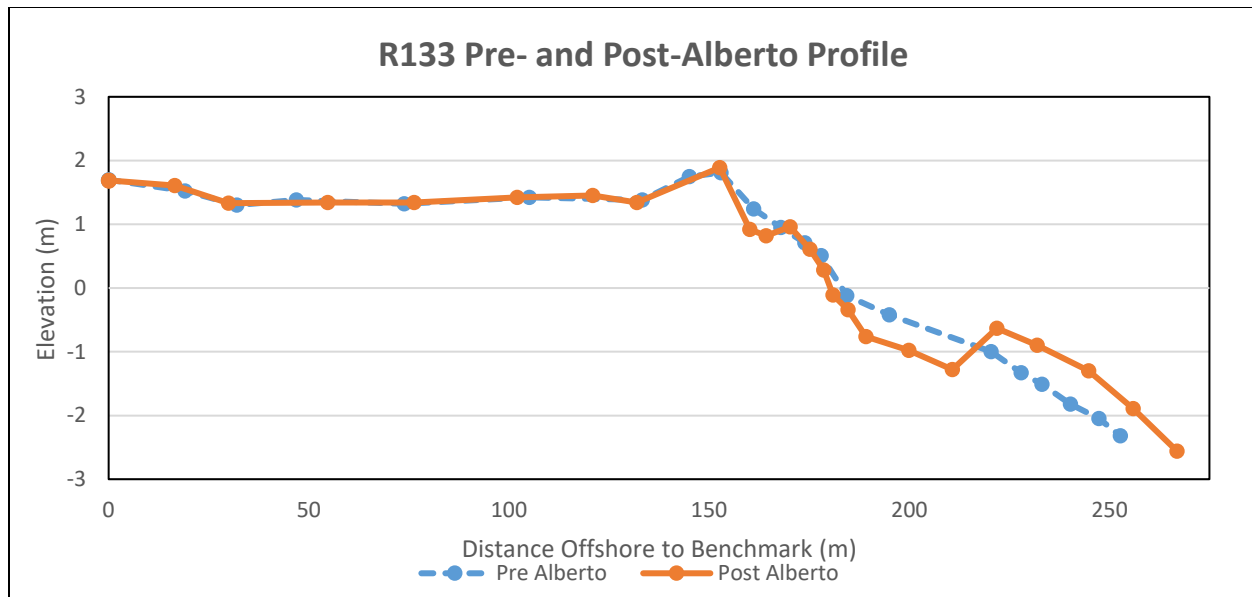
A nourishment project was conducted between June to July 2006 from R127 to R129 and from R136 to R141, and as shown in Figure 13, there was minimal change in the beach profile which is likely influenced by the nourishment. A total measured sand loss was approximately 25 m<sup>3</sup>/m. John's Pass ebb delta might also have played a significant role. Due to the special location of R129 just south of the attachment point, large amounts of sediment were transported to the

attachment point, which might have compensated for the sand eroded from tropical storm Alberto.



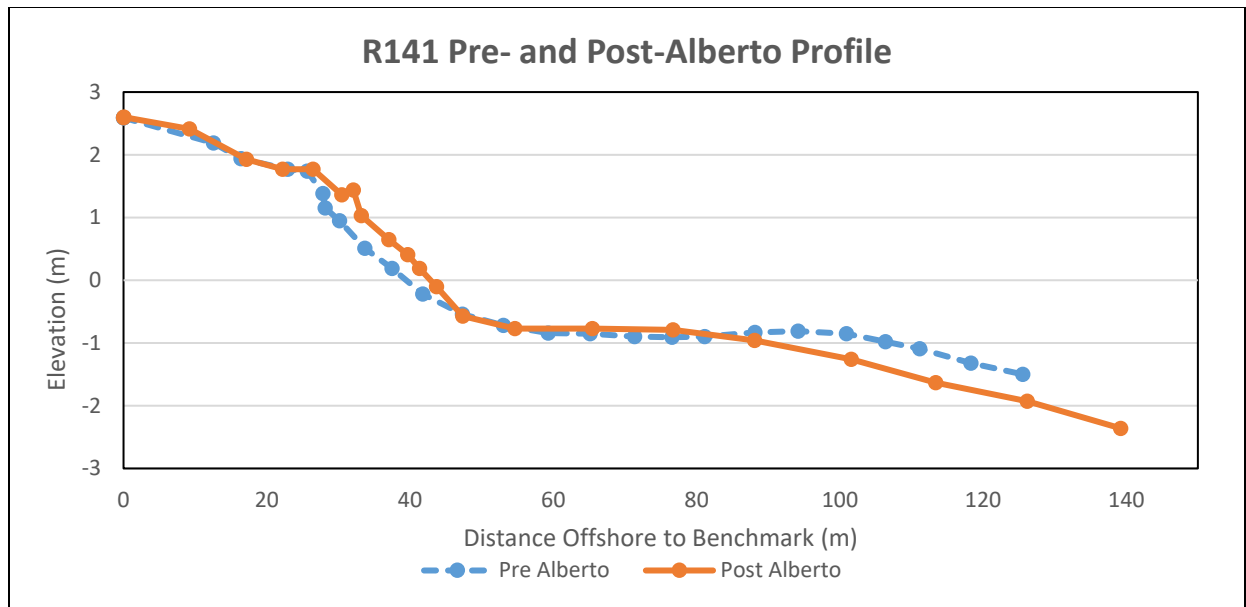
**Figure 13.** Beach profile change at survey line R129 due to Alberto.

Survey line R133 located at the Middle Beach had a 150-meter wide dry beach. According to the pre- and post-storm beach profiles (Figure 14), severe erosion occurred at this section approximately 150 to 200 m away from benchmark, and a sand bar was formed offshore approximately 225 m away from benchmark. At the elevation of 1.0 m, the contour line moved landward approximately 10 m; at the elevation of 0.0 m, the shoreline moved landward approximately 3.4 m; and at the elevation of -1.0 m, the contour line moved landward approximately 20.5 m. The measured sand volume loss was approximately 40 m<sup>3</sup>/m.



**Figure 14.** Beach profile change at survey line R133 due to Alberto.

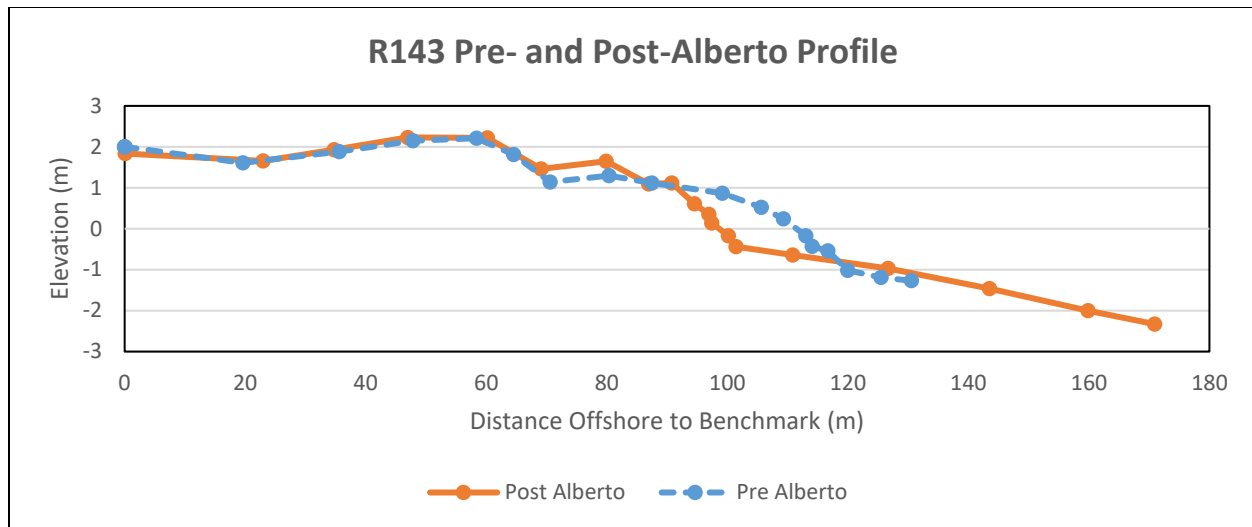
Survey lines R141 and R143 are located at Sunset Beach, the southernmost part of Treasure Island. As mentioned in Chapter 2, the offshore dredged pit directly seaward of these two profiles resulted in higher wave heights as compared to those from adjacent area (Roberts and Wang, 2012). As a result, beach erosion here tends to be more severe than other parts of Treasure Island. However, a nourishment project was conducted from R136 to R141 during the storm. The beach profile at survey line R141 (Figure 15) shows that the contour line of the nearshore section moved seaward and the contour line at offshore section moved landward. At the elevation of 1.0 m, the contour line moved seaward approximately 3 m due to the nourishment project; at the elevation of 0.0 m, the contour line moved seaward approximately 3 m as well; however, at the elevation of -1.0 m, the contour line retreated approximately 18 m. A total measured sand loss at the offshore section was approximately  $14 \text{ m}^3/\text{m}$ . This beach change was influenced by the beach nourishment, as well as by the storm.



**Figure 15.** Beach profile change at survey line R141 due to Alberto.

The survey line R143 experienced severe erosion during the storm (Figure 16). A new berm crest was generated at the location approximately 80 m away from benchmark. The nearshore section moved landward approximately 13 m at the elevation of 0.0 m; at the elevation of -0.5 m, contour line retreated approximately 15 m. A total measured sand volume loss was approximately 25 m<sup>3</sup>/m at survey line R143.

Overall, as a result of induced by tropical storm Alberto, Treasure Island's coast was severely eroded at survey lines R127 and R143. At the elevation of 0.0 m, contour lines at survey lines R127 and R143 retreated approximately 24 m and 13 m, respectively. The contour line of profile R133 at the elevation of 0.0 m retreated approximately 3.4 m. Survey lines R129 and R141 experienced relatively small amounts of erosion according to pre- and post-storm beach profiles. However, these two sections may have experienced severe erosion just as what happened at survey lines R127 and R143. The erosion at these two sections may have been compensated by the ongoing nourishment projects.



**Figure 16.** Beach profile change at survey line R143 due to Alberto.

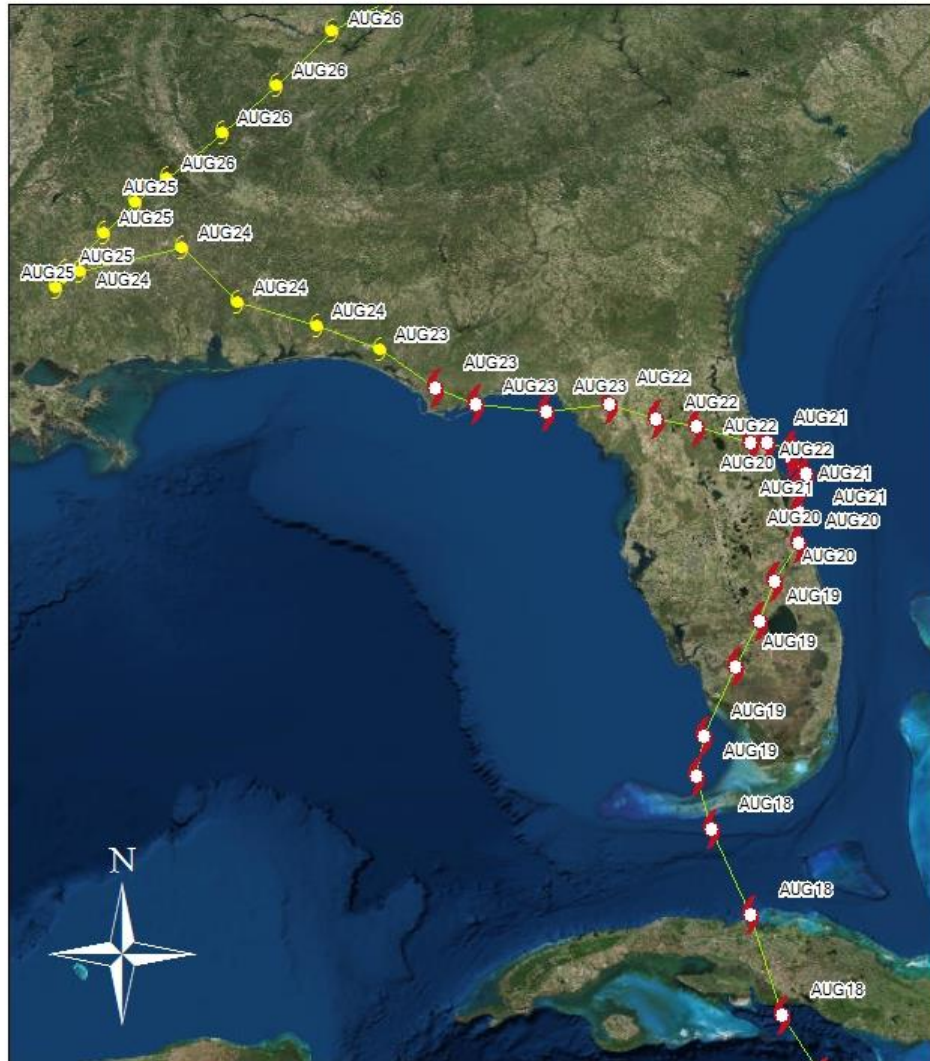
#### 4.2 Beach Profile Changes Induced by Tropical Storm Fay, 2008

Fay was a long-lasting tropical storm with a total of eight landfalls, including 4 landfalls in Florida, U.S. Fay caused severe flooding across the Dominican Republic, Haiti, Cuba and Florida (NOAA). Fay formed from a tropical wave along the African coast on August 6, 2008 and moved rapidly across Atlantic Ocean. According to the Dvorak satellite's estimation and classification method, the tropical wave formed a tropical depression on August 15 and headed northwestward. After making landfall near El Cabo, Dominican Republic, the system became a tropical storm based on the observation from Air Force Reserve Unit and a NOAA aircraft (Stewart and Beven, 2009). Fay moved westward across Gonav Island, Haiti and Windward Passage, and then turned west-northwestward across Cuba. Fay made its first landfall in the State of Florida near Key West on August 19, 2006. The storm became better organized after passing Key West over the warm waters of Florida Bay and made a second landfall in Florida between Cape Romano and Everglades City on August 19, 2004 (Stewart and Beven, 2009). Fay moved northeastward inland and turned westward after crossing Florida. Fay made another landfall in

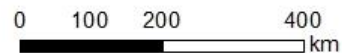
Florida near Flagler Beach on August 21 and then the storm crossed Florida again moving westward. Figure 17 shows the track positions for tropical storm Fay. The storm brought heavy rainfall and localized flooding. Storm surge from Fay were relatively minimal, and generally varied between 30 and 60 cm above NAVD88 along South Florida's coast (NOAA). Tropical storm Fay generated a total of 81 tornadoes in the U.S., including 19 in Florida, and caused 5 deaths in state of Florida among 13 deaths in total. Most damage was caused by flood induced by heavy rainfall (NOAA). Wave height and water level were raised as well due to the large amounts of rainfall all over the state, including the study area.

Tropical storm Fay impacted the study area from August 15 to 27, 2008 with a mean wind speed of 5.60 m/s. The mean water level during the storm was 0.556 m and mean wave height was 1.08 m. Tropical storm Fay was special due to its path and landfall locations. Fay made landfall east of Cape Romano, FL on August 19, which is located approximately 260 km south of the study area, and then moved inland and weakened. After four days of travelling over land, Fay moved back to the Gulf of Mexico north of Steinhatchee, FL, which is located approximately 230 km north to study area. At that time, the storm surge was approximately 0.2 m. Water level remained same level approximately 0.58 m. However, mean wind speed was 2.78 m/s and mean wave height was 0.60 m. Comparing the two sets of data, mean wave height increased approximately 81.5% and mean wind speed increased approximately 1.02 times. Although mean water level did not change much, the maximum wind speed during the storm increased from 10.4 m/s to 15.4 m/s. Figure 18 and Figure 19 illustrate the measured data during tropical storm Fay and the period of one month before Fay, respectively (NOAA).

## Track of Fay 2012



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



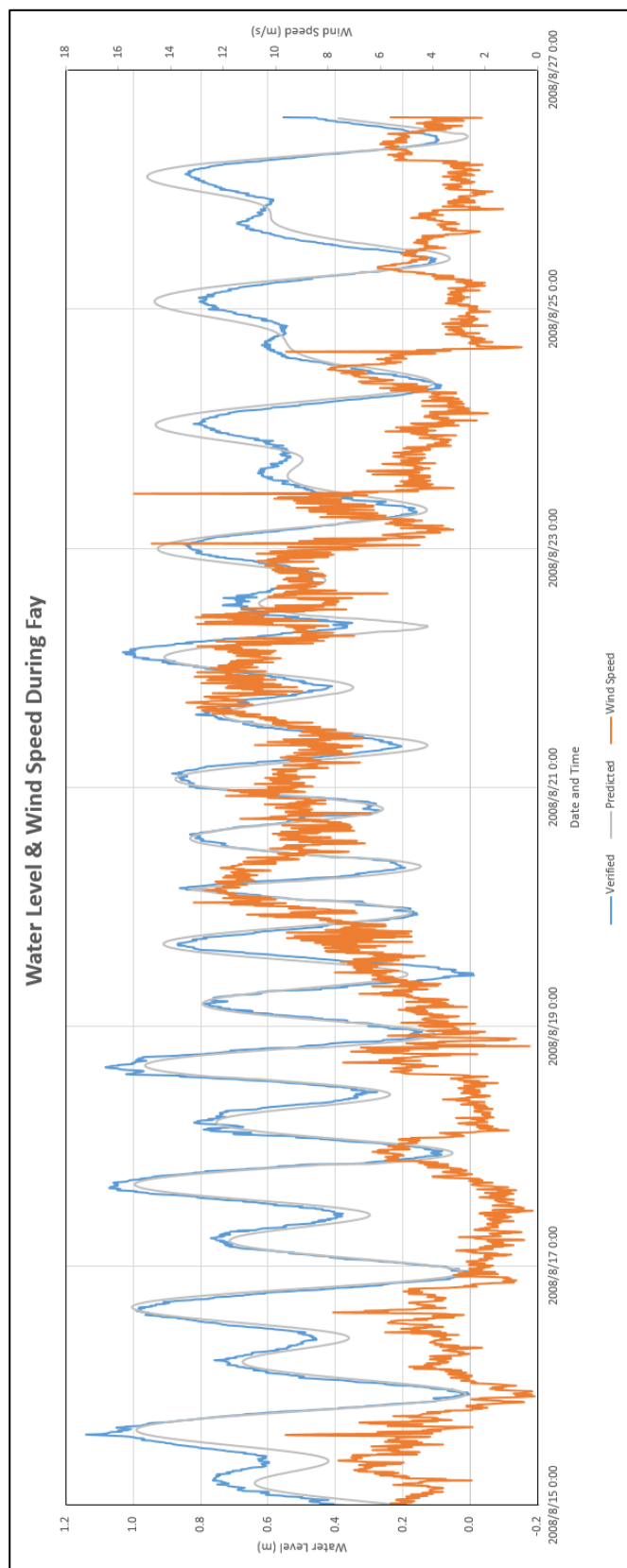
Source: National Hurricane Center  
Made by: Zhaoxu Zhu  
Date: 9/30/2016

**Figure 17.** Track positions for Tropical Storm Fay, 15-26 August 2008 (Stewart and Beven, 2009).

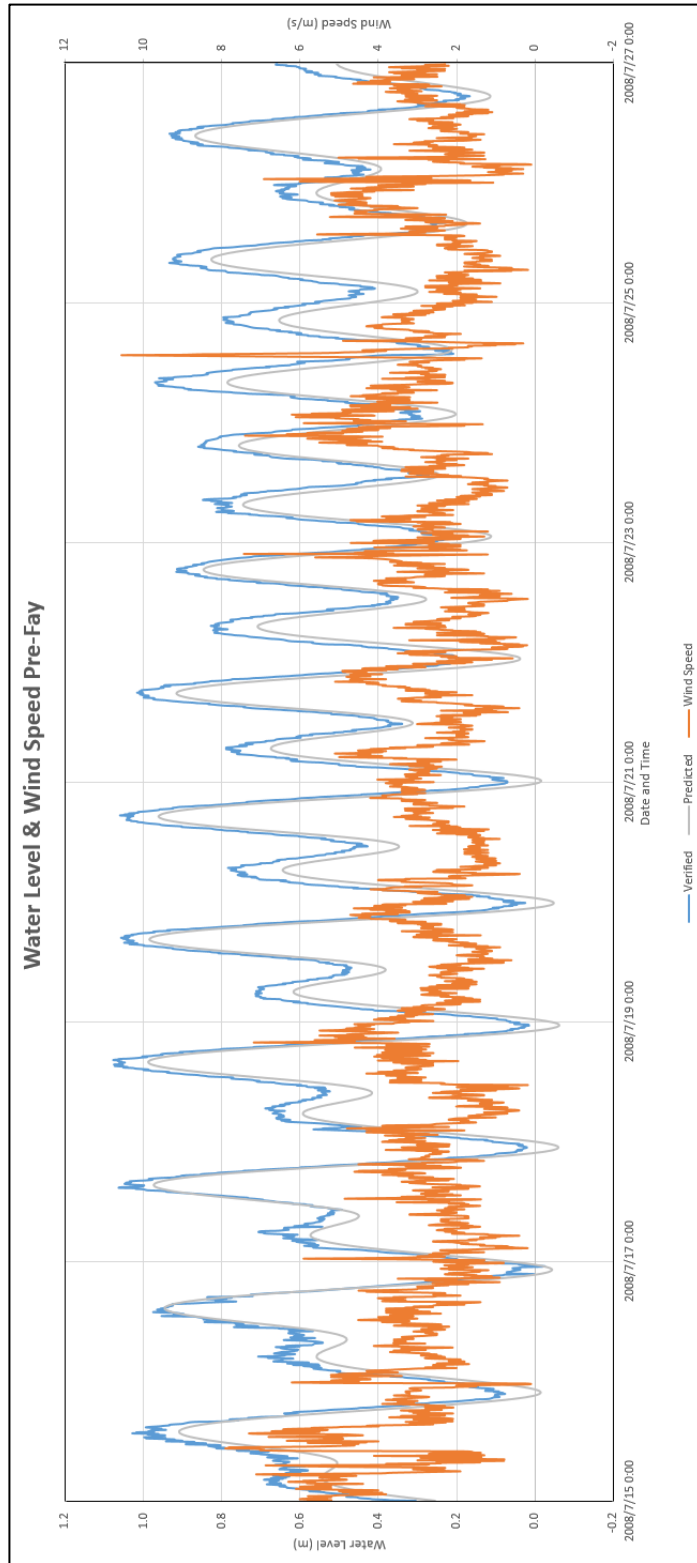
As shown in Figure 17 and Figure 18, between August 15 and August 19, as Fay moved landward from the Gulf of Mexico, a storm surge of around 0.18 m occurred at approximately 6:00 a.m. on August 15 and another storm surge at approximately 0.2 m occurred at approximately 6:00 a.m. on August 19. During this period of time, storm surge varied from 0.03 m to 0.2 m. Wind speed varied below 10 m/s. After landfall, storm surge decreased to normal level until August 22, 2008. Wind speed varied from approximately 7 m/s to 13.5 m/s between August 15 and August 19, which was higher than the average wind speed. From August 22, Fay moved seaward from inland at central-north Florida. The wind speed at the study area increased to a maximum of 15.4 m/s on August 23 and storm surge reached a maximum of 0.26 m at approximately 12:00 a.m. on August 22. After August 24, wind speeds decreased to an average level of 4 m/s and there was negative surge.

Due to Fay's complicated path and landfall area, water level and storm surge may not be good controlling factors of storm impact on the beach changes in the study area. Therefore, wave height is discussed here as another controlling factor (Figure 20, see page 32). Wave height increased rapidly on August 19 and remained over 1 m for 5 days between August 19 and August 24, 2008. When Fay moved seaward into the Gulf of Mexico, wave heights reached up to 2.37 m around 11:00 a.m. on August 22. After Fay moved away, wave height decreased to approximately 1 m.

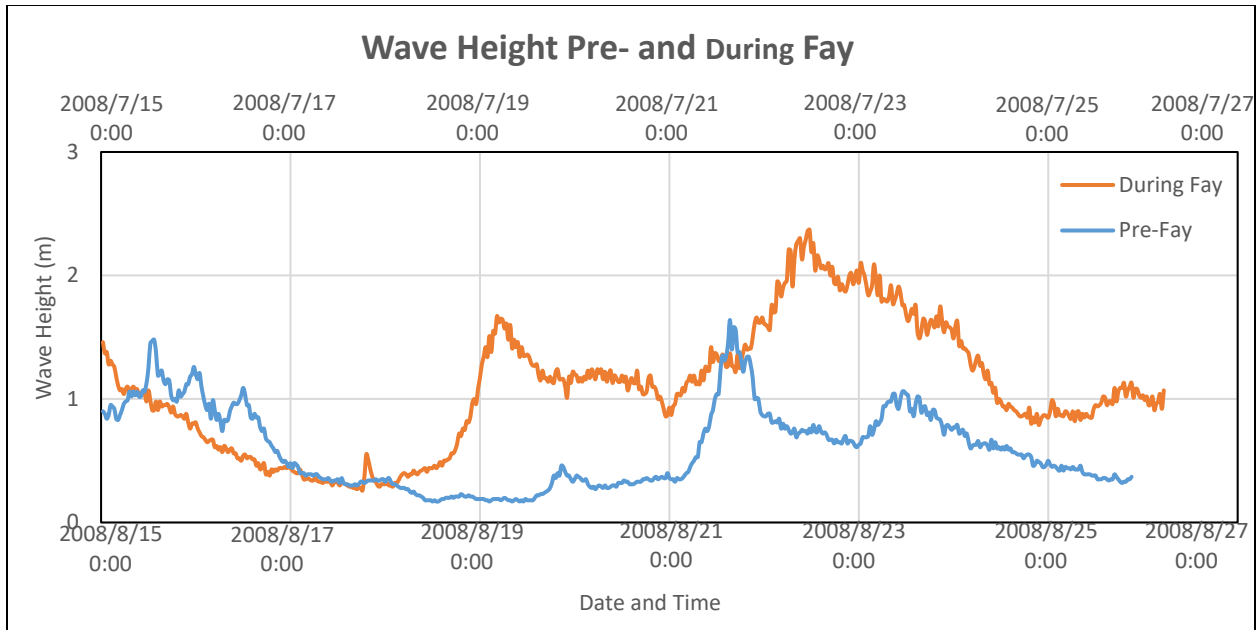




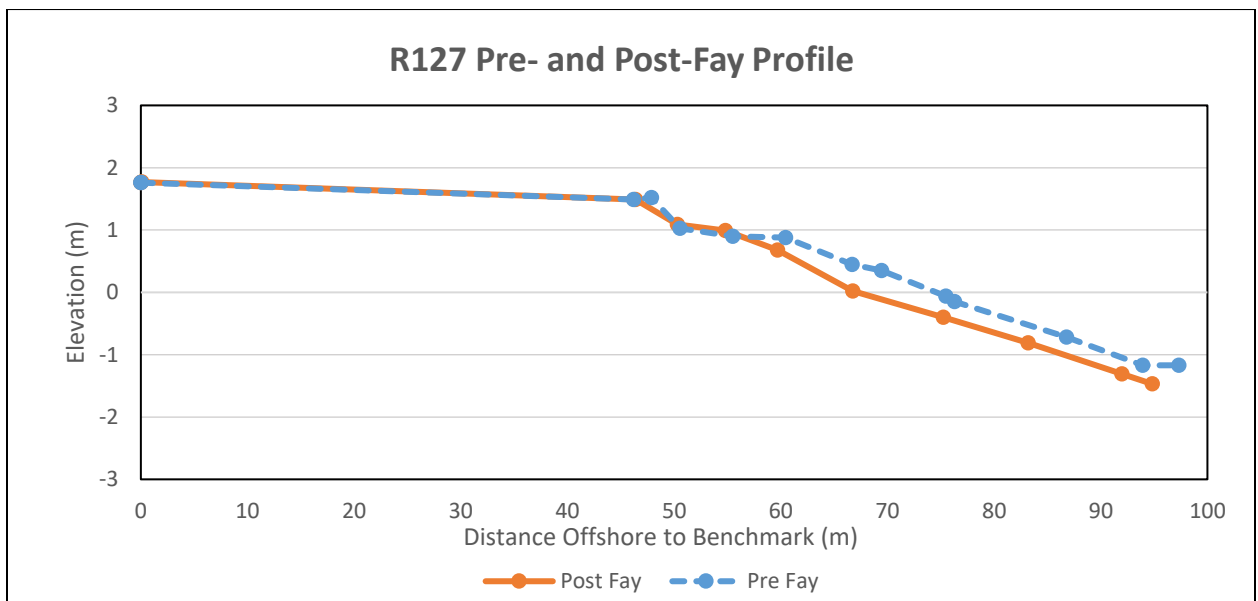
**Figure 18.** Water level and wind speed during tropical storm Fay, 15-27 August, 2008.



**Figure 19.** Water level and wind speed pre-tropical storm Fay, 15-27 July, 2008.



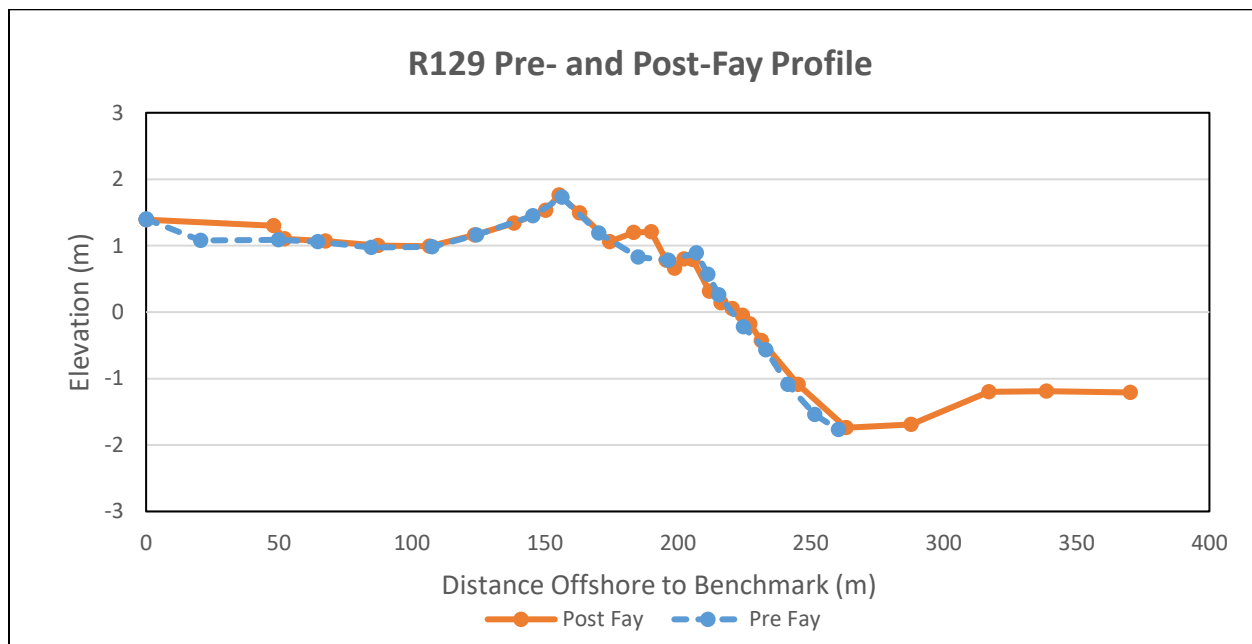
**Figure 20.** Wave height pre- and during Fay, measured at Station 42099 by NOAA's NDBC.



**Figure 21.** Beach profile change at survey line R127 due to Fay.

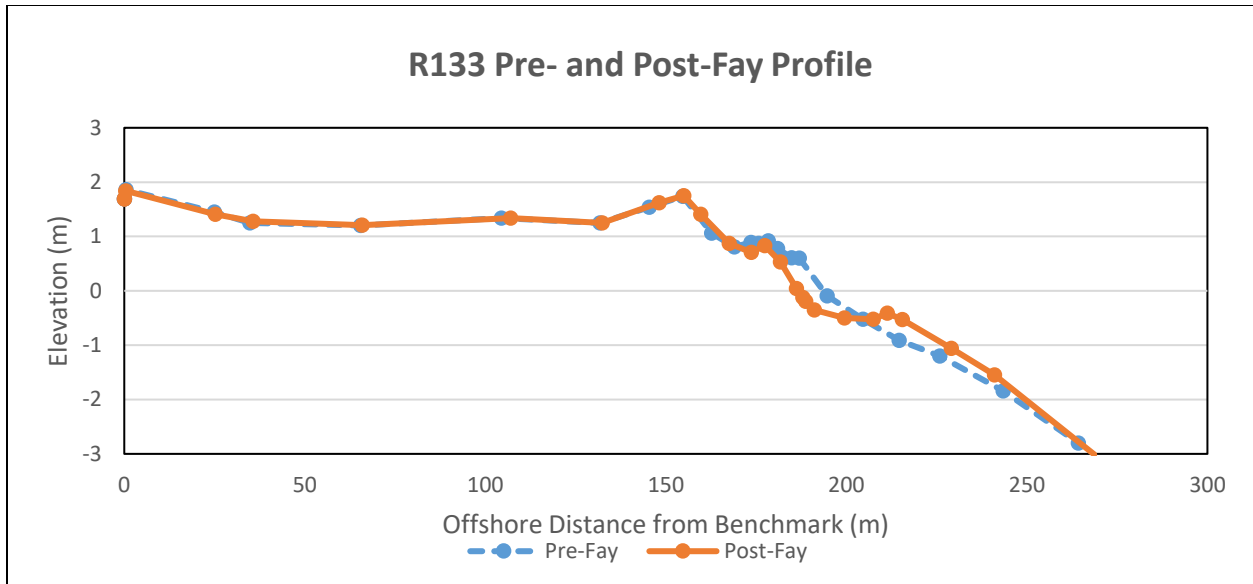
As a result of fairly normal wind speeds and minimal storm surge, Sunshine Beach at profile R127 was not significantly eroded (Figure 21). At the elevation of 1.0 m, the contour line moved approximately 2 m landward; at the elevation of 0.0 m, the contour line retreated

landward approximately 8 m; and at elevation of -1.0 m, the contour line moved approximately 5 m landward. The total measured sand loss was approximately 12 m<sup>3</sup>/m. Similarly, at survey line R129, the erosion was not significant (Figure 22). The dune did not change much; a new berm crest was generated at the location approximately 190 m away from the benchmark; the nearshore area was slightly eroded and the slope became gentler than it was before the storm.

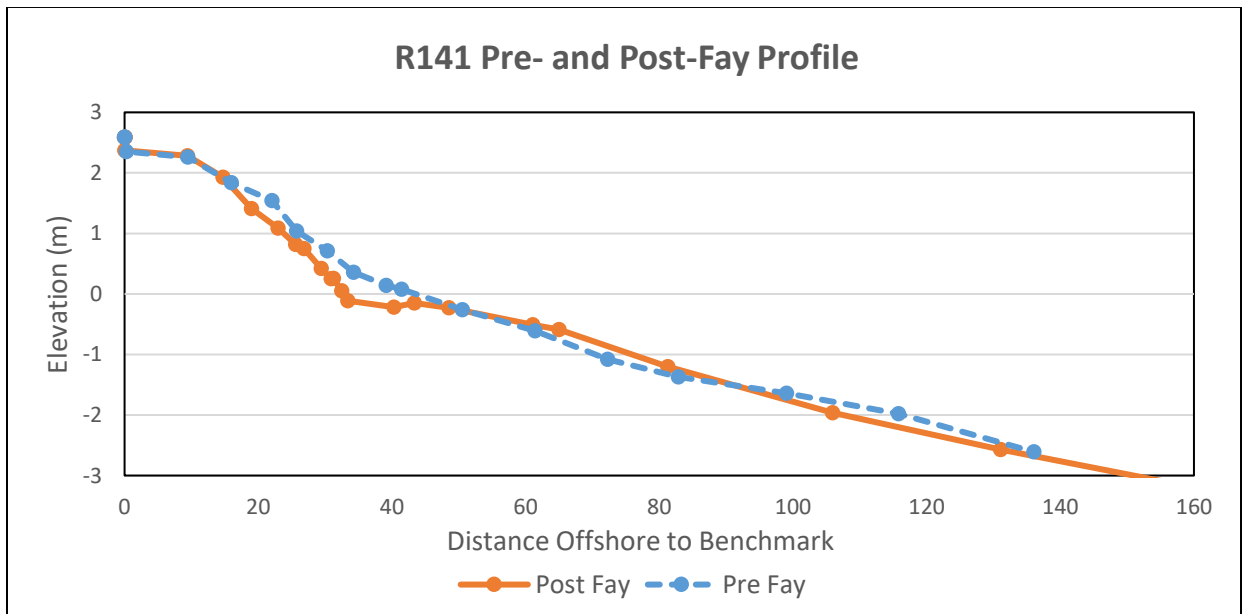


**Figure 22.** Beach profile at survey line R129 due to Fay.

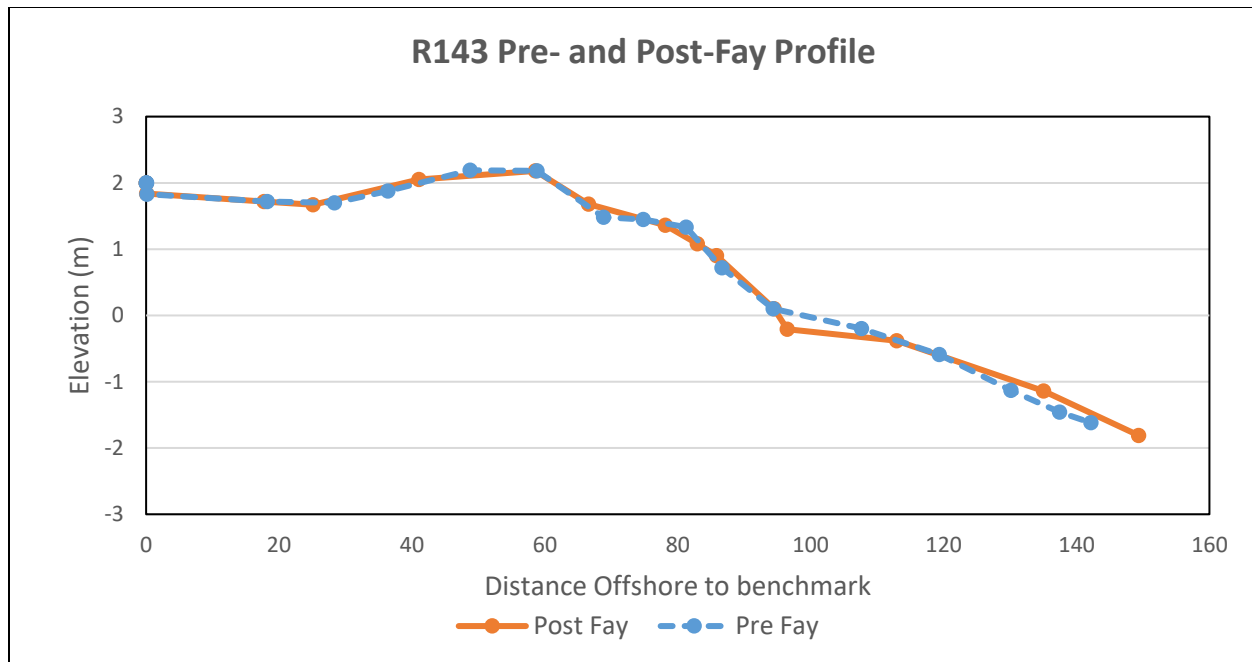
No significant erosion occurred at profile R133 (Figure 23). There was no significant change to dry beach and dune area. The nearshore zone at the section from 180 to 200 m away from benchmark lost a small amount of sand. At an elevation of 0.0 m, the contour line move landward approximately 5 m. At the offshore area, from location of 210 to 250 m away from the benchmark, a small amount of deposition was gained, which balanced the sand loss in the nearshore zone.



**Figure 23.** Beach profile change at survey line R133 due to Fay.



**Figure 24.** Beach profile change at survey line R141 due to Fay.



**Figure 25.** Beach profile change at survey line R143 due to Fay.

Beach changes at profiles R141 and R143 were similar (Figure 24 and Figure 25). At line R141, the nearshore area was the most severely eroded section along this profile. The total measured sand loss was approximately 8 m<sup>3</sup>/m. R143 almost remained the same characteristics as before storm. A subtle berm was formed at approximately 75 m away from benchmark. The nearshore section at approximately 95 to 110 m away from benchmark was eroded and the sand was deposited offshore approximately 120 to 140 m away from benchmark.

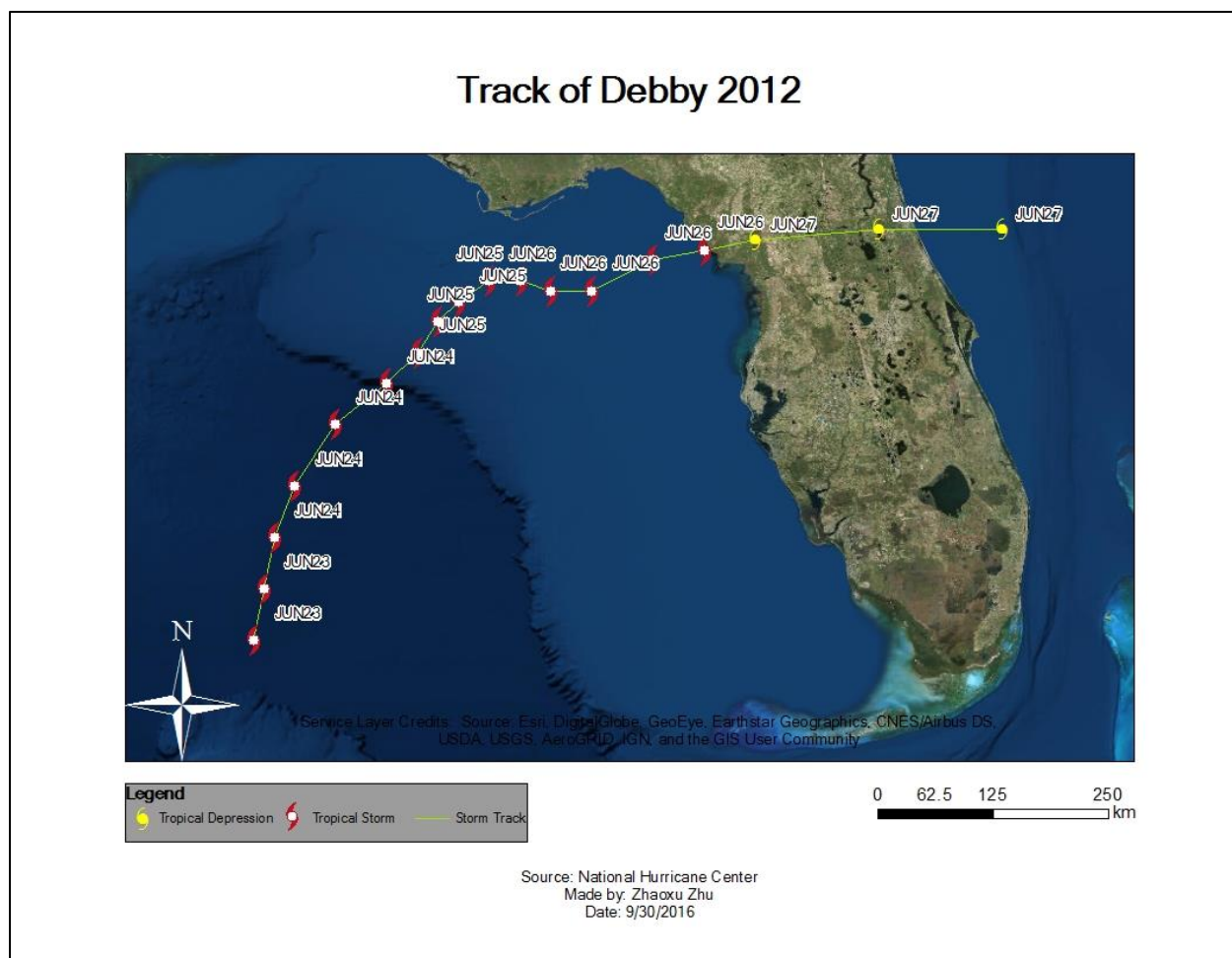
Overall, tropical storm Fay is a different case from the previous storms due to its path that was quite far from the study area. Wind speed and water level were not significantly increased during this storm. When Fay was approaching the mainland of Florida, wave height increased rapidly. After landfall at south Florida, wave heights remained relatively high as well. As the storm moved back to the Gulf of Mexico, wave heights increased to the maximum value. However, the entire Treasure Island coastline was not significantly eroded because the landfall

area was far away from study area and Fay did not induce a significant surge. Sunshine Beach experienced modest erosion. Minor erosion occurred at the middle section of Treasure Island (e.g., at R133); Sunset Beach experienced minor erosion in the nearshore zone.

#### 4.3 Beach Profile Changes Induced by Tropical Storm Debby, 2012

The development of tropical storm Debby was slow. Debby was first formed from a trough of low pressure which was generated in the Gulf of Mexico on June 22, 2012. According to the data collected by an Air Force Reserve Hurricane Hunter aircraft, a tropical storm was formed on June 23 around 12:00 a.m. (Kimberlain, 2013). Debby gradually moved north-northeastward from June 24 to 26 and made landfall at Steinhatchee, Florida. Between June 26 to 27, Debby crossed north-central Florida, weakened and became a tropical depression. Figure 26 shows the track of tropical storm Debby from June 23 to June 27.

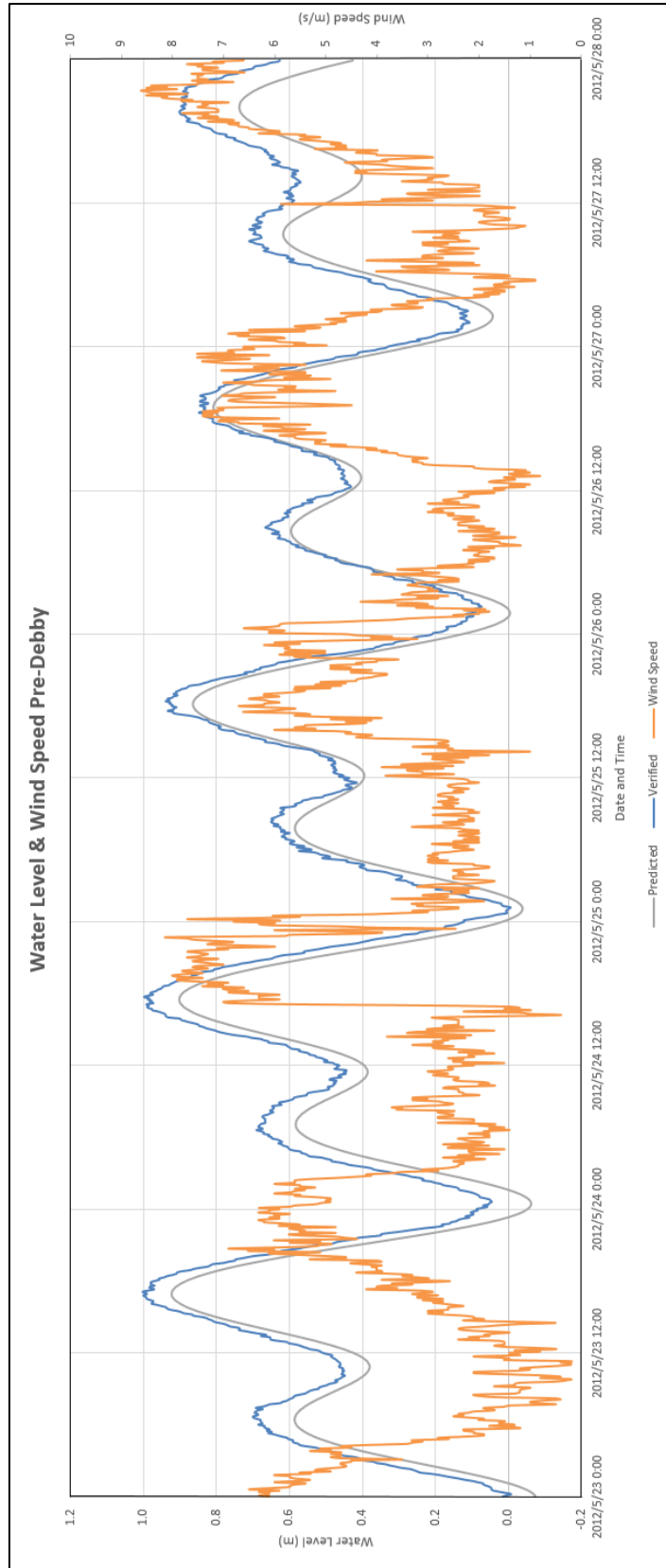
Debby made landfall approximately 170 km north of the study area. As compared to Alberto's landfall in 2006, Debby's landfall site was closer to the study area. In addition, Debby was a rather large storm. The slow moving Debby generated strong winds at a mean speed of 9.61 m/s and the peak storm surge was 0.95 m in the study area. The mean water level during the storm was 1.02 m and the mean wave height was approximately 2.56 m. Figure 27 illustrates the water level and wind speed one month before Debby. Figure 28 illustrates the water level and wind speed during the storm. Pre-Debby wind speed varied from a minimum 0.2 m/s to a maximum 8.6 m/s. The maximum surge was 0.22 m related to typical summer low pressure conditions. When Debby moved past the study area, the maximum wind speed reached 19.6 m/s and the peak storm surge was 0.95m. Comparing these two sets of data, the mean wind speed increased 1.28 times during the storm; mean water level increased 0.86 times; and mean wave height increased 4.5 times during the storm.



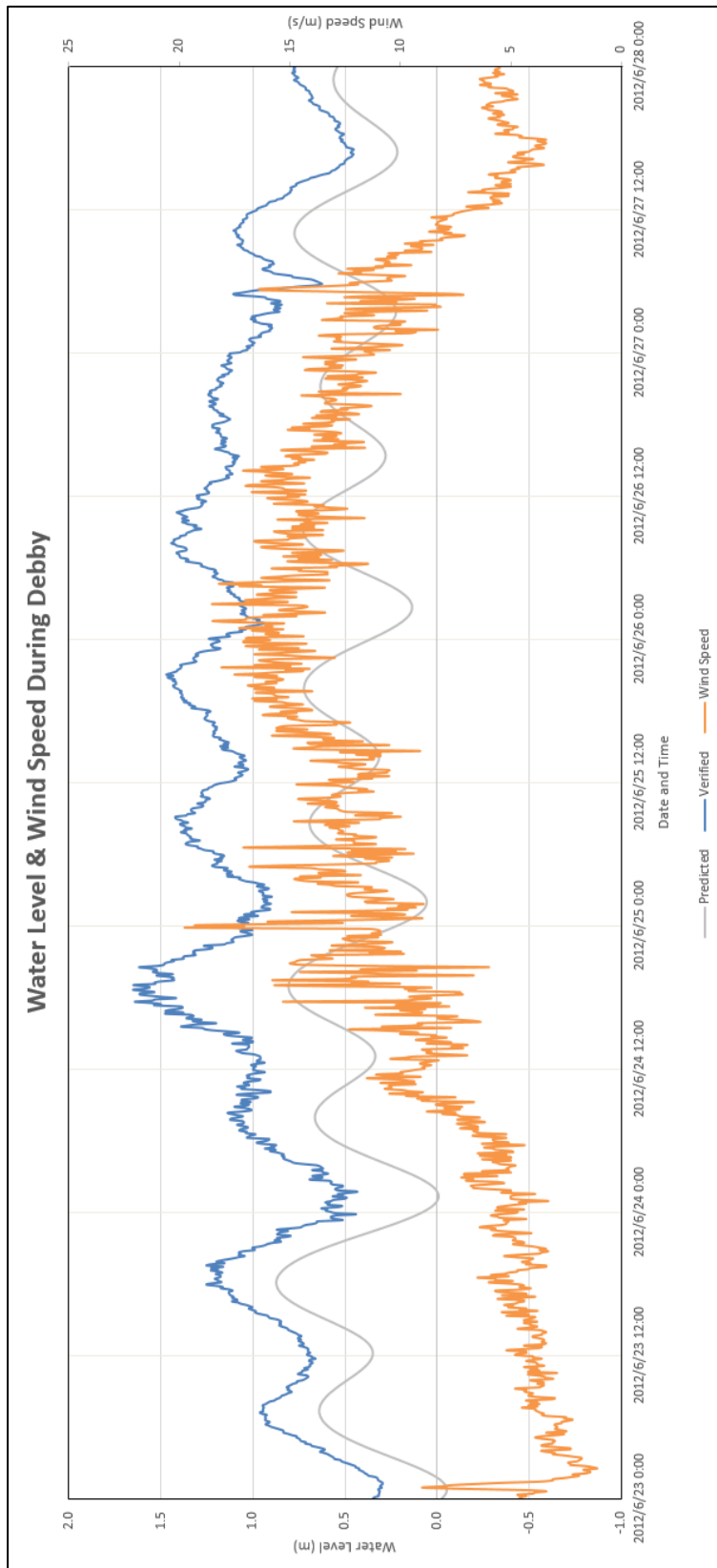
**Figure 26.** Track positions of tropical storm Debby, 23-27 June.

Superimposed on strong winds and high storm surge, energetic waves played a significant role in eroding the Treasure Island beach. Figure 29 (See page 40) illustrates wave height changes during tropical storm Debby and one month before Debby, respectively. When the storm was formed on June 23<sup>rd</sup>, wave height increased rapidly from 1 m to 4 m. Wave height reached the maximum of 5.06 m the next day. From June 25<sup>th</sup> to 27<sup>th</sup>, wave heights decreased slowly, however, wave height was still much higher than the normal level. After Debby moved inland, wave height decreased to the pre-storm level.

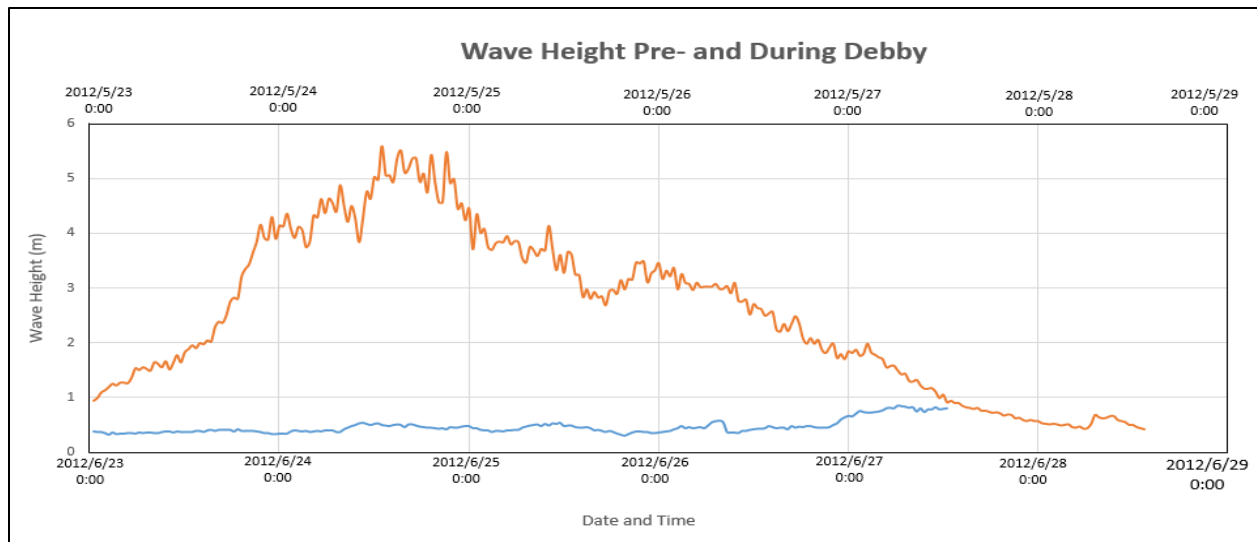




**Figure 27.** Water level and wind speed pre-tropical storm Debby, 23-28 May, 2012.



**Figure 28.** Water level and wind speed post tropical storm Debby, 23-28 May, 2012.

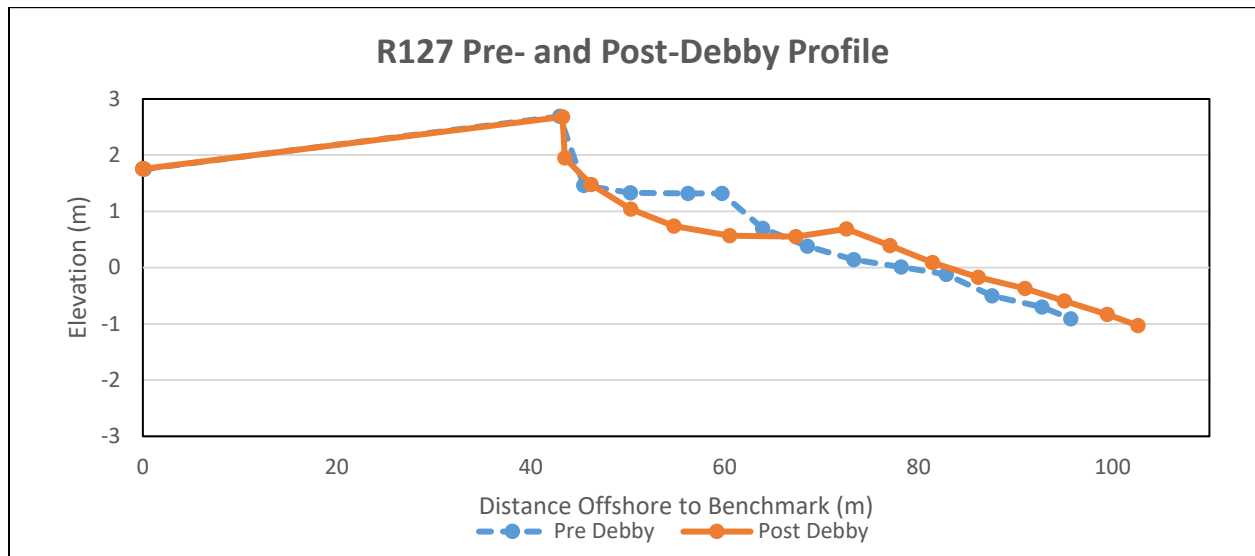


**Figure 29.** Wave height changes pre- and during tropical storm Debby.

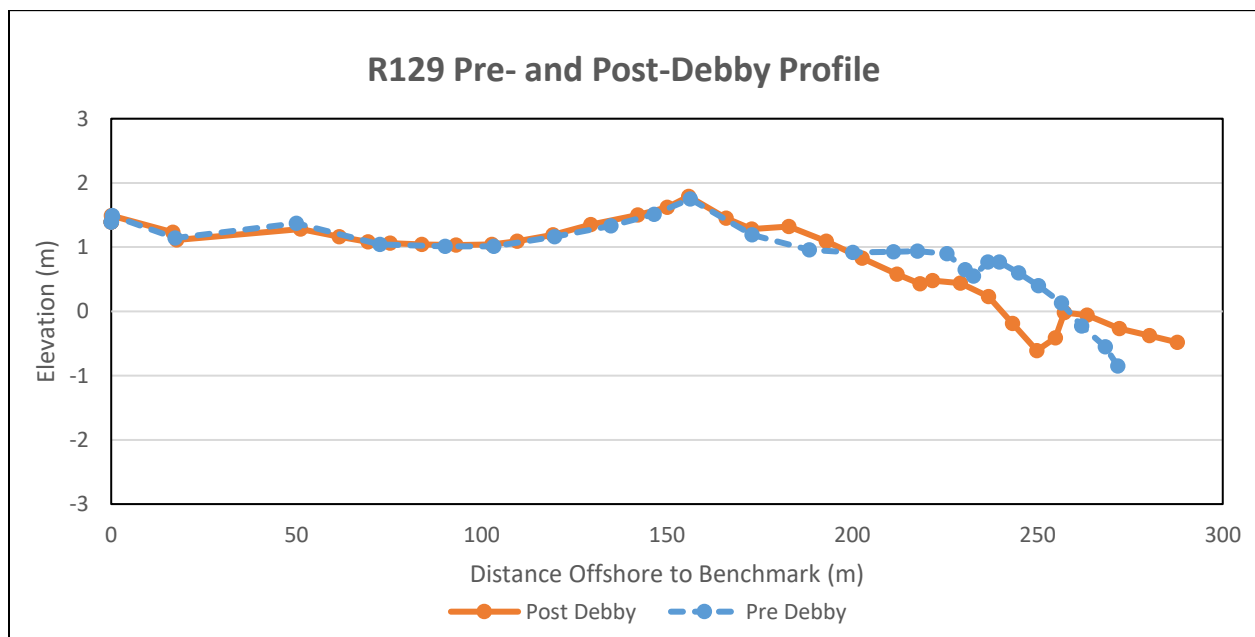
Due to the high wave, strong wind and large storm surge, Treasure Island experienced severe beach erosion, especially along Sunset Beach (Wang and Roberts, 2012). Figure 30 shows beach profile changes at survey line R127. Profile R127 was severely eroded mainly on the dry beach area. The pre-storm dune scarp was sharpened at the location approximately 45 m away from the benchmark. The back beach area between 45 m and 60 m was eroded away while the nearshore zone gained sediment. At the elevation of 1.0 m, the beach profile moved landward approximately 10 m; at the elevation of 0.0 m, the contour line moved approximately 2 m seaward; and at the elevation of -1.0 m, the profile moved approximately 5 m seaward.

The beach at profile R129 suffered severe erosion in the nearshore zone (Figure 31). A storm berm was developed at approximately 175-190 m away from benchmark with the sand that was eroded from the dry beach area. The nearshore zone from 200 to 230 m away from benchmark suffered the most severe erosion. A ridge and runnel system was developed at approximately 250 m suggesting the post-storm beach recovery had started at this location at the time of the post-storm survey. At the elevation of 1.0 m, the contour level moved seaward

approximately 5 m; at the elevation of 0.0 m, the shoreline retreated landward approximately 20 m; and at the elevation of -0.5 m, the profile move seaward approximately 20 m.



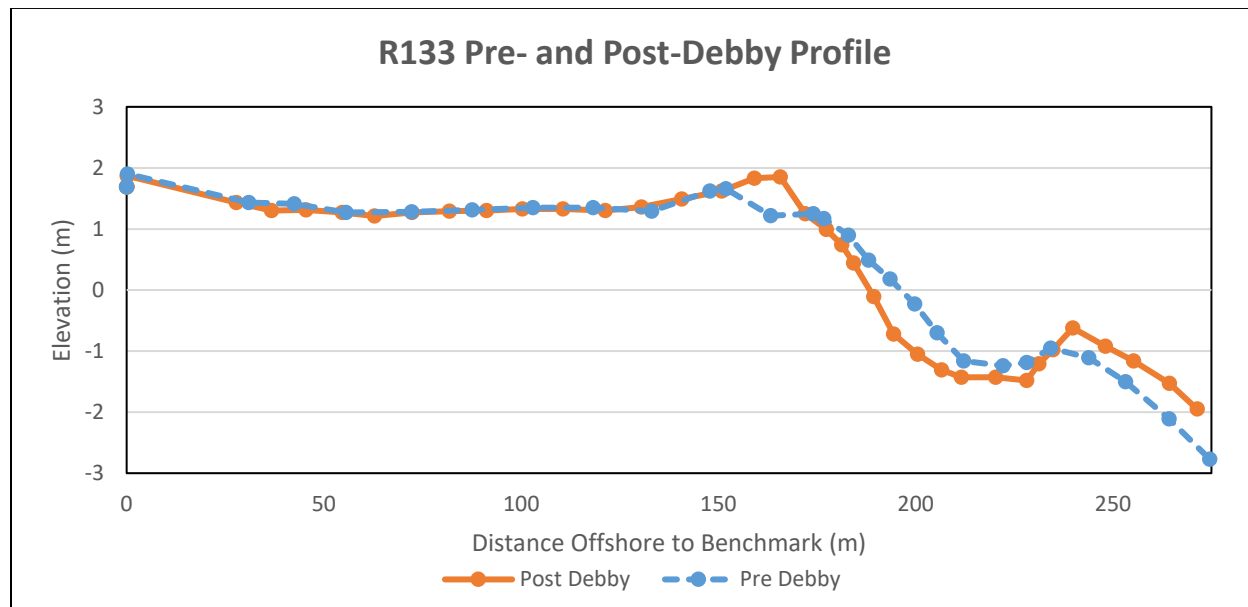
**Figure 30.** Beach profile change at survey line R127 due to Debby.



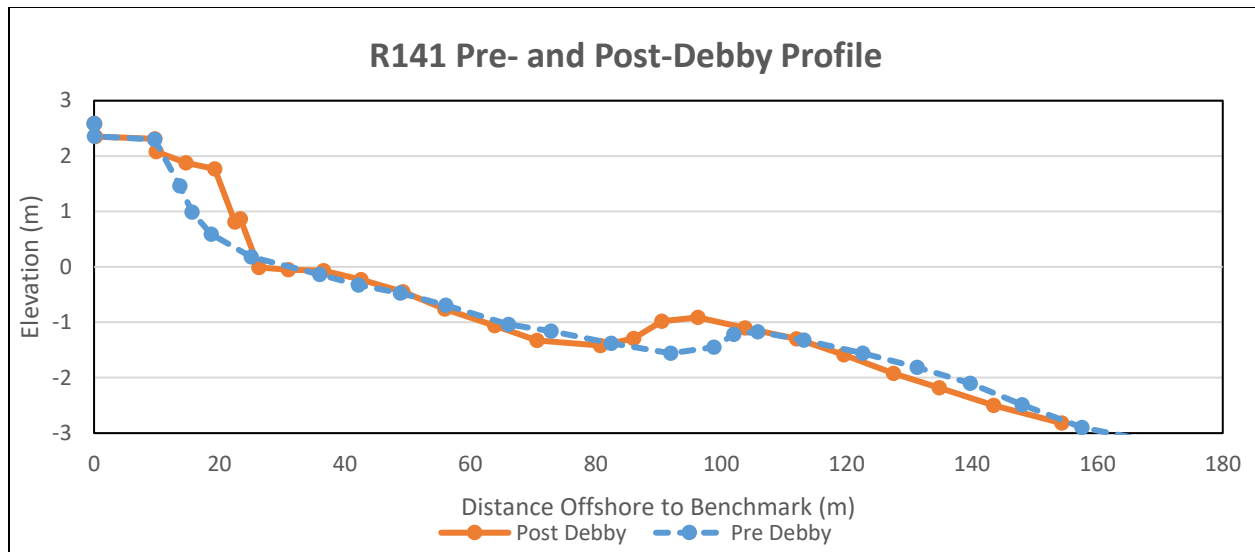
**Figure 31.** Beach profile change at survey line R129 due to Debby.

Along the middle section of Treasure Island, the nearshore zone suffered severe erosion and the sand bar at approximately 240 m away from benchmark gained sediment and moved seaward (Figure 32). At the elevation of 1.0 m, the contour line moved landward approximately 6 m; at the elevation of 0.0 m, the profile moved landward approximately 5 m; and at the elevation of -1.0 m nearshore, the contour line retreated approximately 5 m landward.

A dune scarp was formed at profile R141 (Figure 33). The nearshore zone experienced slight erosion. The sandbar crest moved onshore approximately 13 m. The offshore zone was also slightly eroded. At the elevation of 1.0 m, the profile moved seaward approximately 8 m and a scarp was formed; at the elevation of 0.0 m, the contour line retreated approximately 3 m landward; and at the elevation of -1.0 m, the sand bar moved landward approximately 13 m.

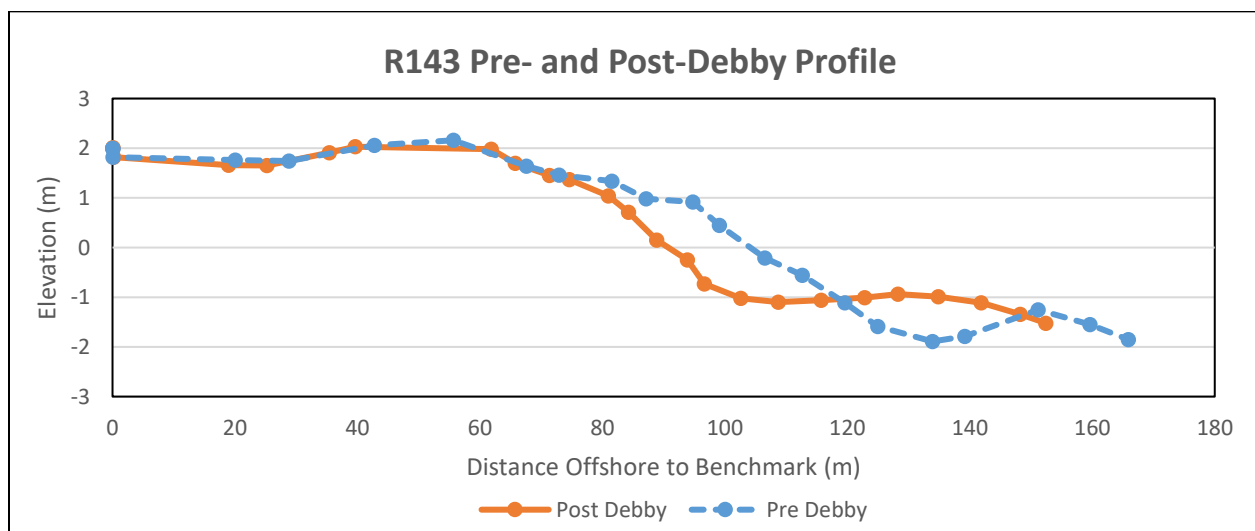


**Figure 32.** Beach profile change at survey line R133 due to Debby.



**Figure 33.** Beach profile change at survey line R141 due to Debby.

At the southernmost part of Sunset Beach, survey line R143 experienced severe erosion (Figure 34), and the nearshore zone lost a large amount of sediment. At the elevation of 1.0 m, the contour line retreated approximately 8 m landward. At elevation of 0.0 m, the contour line moved approximately 12 m landward. At elevation of -1.0 m, the contour line retreated approximately 20 m landward. Overall, measured sand loss was approximately 20 m<sup>3</sup>/m.



**Figure 34.** Beach profile change at survey line R143 due to Debby.

Overall, tropical storm Debby caused substantial erosion at the dune, dry beach and nearshore zones along the entire Treasure Island shoreline (Wang and Roberts, 2012). Dune scarping occurred at survey line R127 and R141 where the pre-storm beach was quite narrow. Almost all the survey lines experienced nearshore erosion.

#### 4.4 Beach profile changes induced by tropical storm Hermine, 2016

Tropical storm Hermine was first captured by a NOAA Hurricane Hunter aircraft as a tropical depression in the Florida Straits and was defined as a tropical cyclone on August 28, 2016. The system moved westward slowly with thunderstorm activities. The tropical depression turned to north-northeastward on August 20 with an unclear center. It is recorded by NOAA's aircraft that heavy rain was falling in Cuba and the depression became better organized and became a tropical storm on August 31 (NOAA). Landfall was made along the coast of Apalachee Bay, Florida at around 11 p.m. on September 1<sup>st</sup> 2016. The storm crossed eastern Florida into southeastern Georgia the next day (NOAA). Figure 35 shows the track of tropical storm Hermine which is similar to the track of Alberto, although landfall area is slightly further away from the study area. However, Hermine was a much stronger storm than Alberto. High waves and strong wind were generated in the Gulf of Mexico, which induced severe erosion along the coast of Treasure Island.

## Track of Hermine 2016



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



0 75 150 300  
km

Source: National Hurricane Center  
Made by: Zhaoxu Zhu  
Date: 9/30/2016

**Figure 35.** Track position of tropical storm Hermine.



For this study, data from August 28<sup>th</sup> to September 2<sup>nd</sup> 2016 were downloaded from NOAA's NDBC website. During this period of time, the mean wind speed of Hermine was 5.99 m/s; mean storm surge was 0.34 m; and mean wave height was 2.25 m. Data from July 28<sup>th</sup> to August 2<sup>nd</sup> are considered as the normal conditions. During that period of time, the mean wind speed was 2.6 m/s; mean surge was 0.17 m; and mean wave height was 0.42 m. Comparing these two sets of data, wind speed increased approximately 1.29 times during the storm as compared to normal conditions; storm surge was twice as high; water level was 0.218 m higher; and wave height was 1.83 m higher on average.

Figure 36 and Figure 37 illustrate wind speed pre- and during Hermine, respectively. Figure 38-1 and Figure 38-2 show the water level pre- and during Hermine, respectively. From August 28<sup>th</sup> to August 31<sup>st</sup>, Hermine was moving towards north Florida. Wind speed was faster than normal level at the study area. Meanwhile, storm surge was increasing. When Hermine approached north Florida coastline and made landfall, wind speed increased and reached 21 m/s at the study area on September 2<sup>nd</sup>. Storm surge reached a height of 1.34 m at the same time.

The pre-storm berm crest was eroded away at survey line R127 at a location approximately 47 m seaward from the benchmark, but no scarp occurred at the dune (Figure 39, see page 50). The nearshore zone received sediment deposition which was probably caused by the impoundment of northerly longshore sediment transport, generated by the highly oblique southerly incident wave. At the elevation of 1.0 m, the dry beach moved seaward for approximately 2 m; at the elevation of 0.0 m, the coastline moved approximately 5 m seaward; and at the elevation of -1.0 m, the nearshore zone moved approximately 12 m seaward. Overall, beach accretion occurred at survey R127.

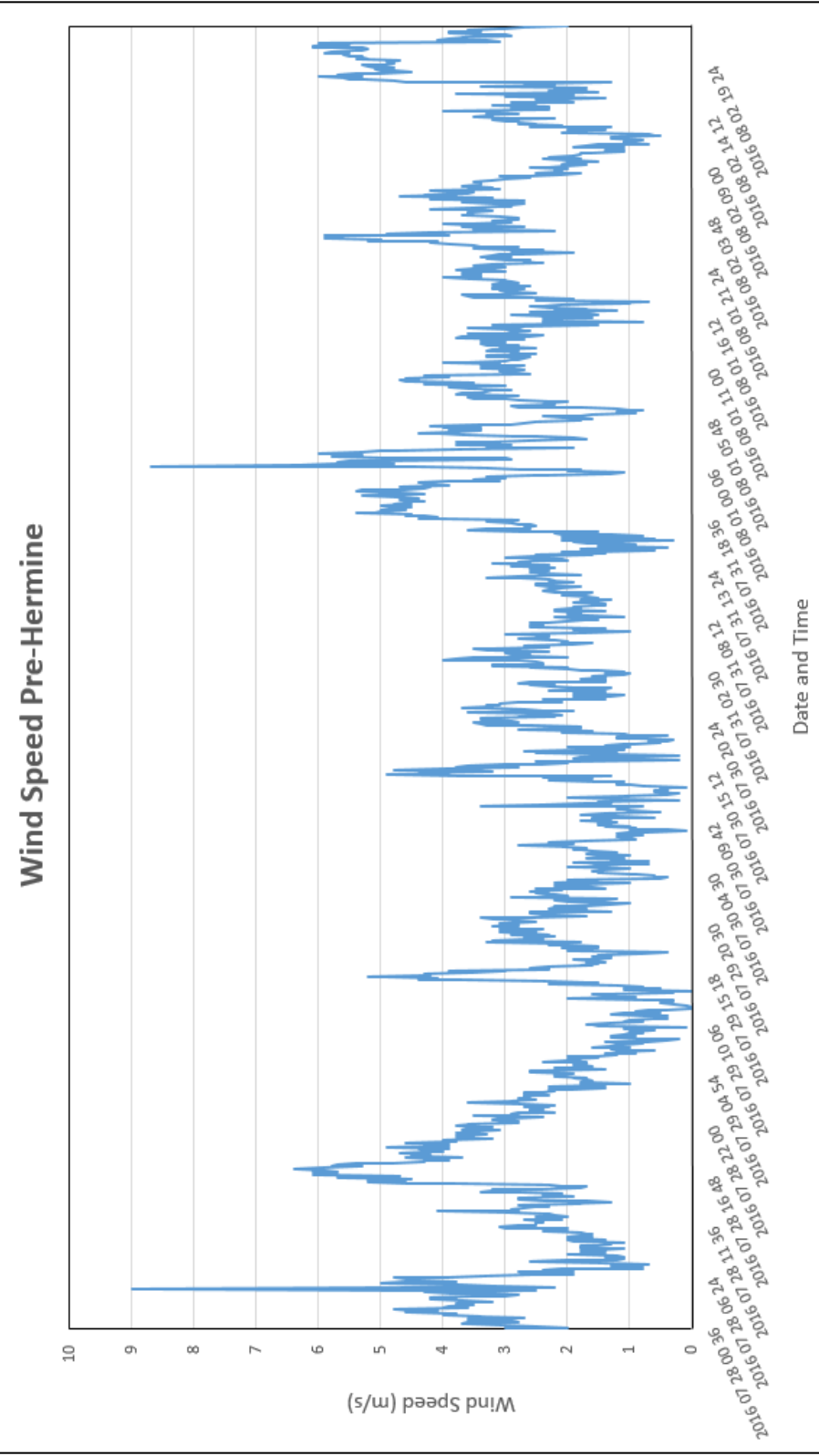
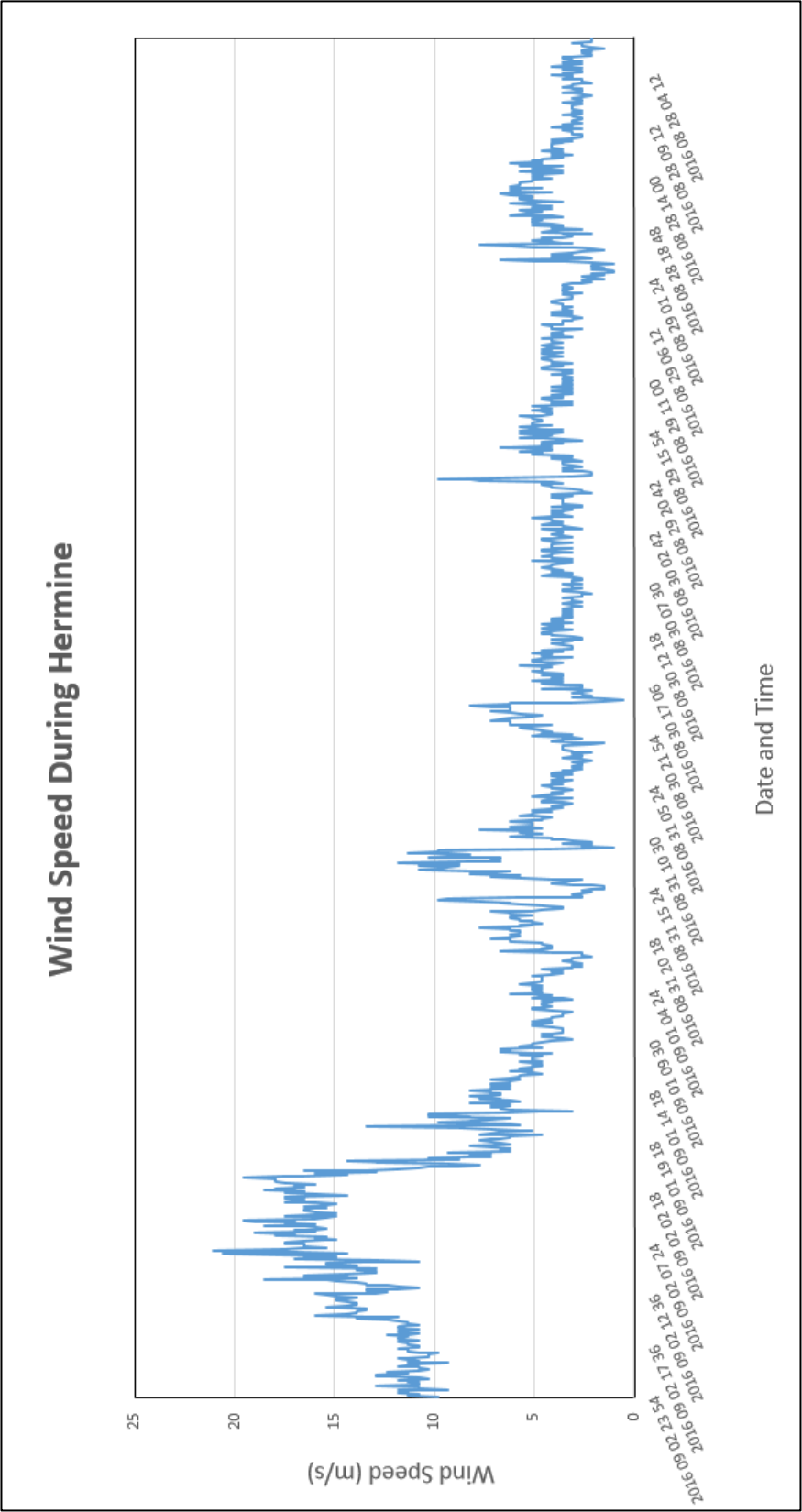
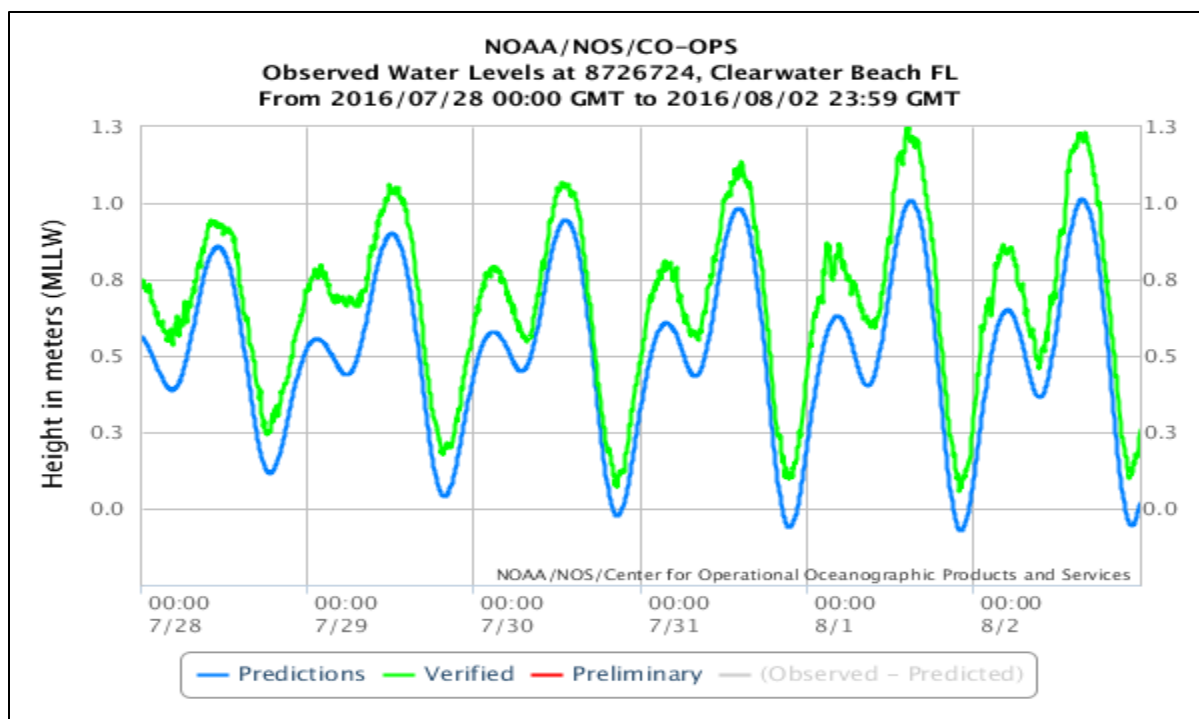
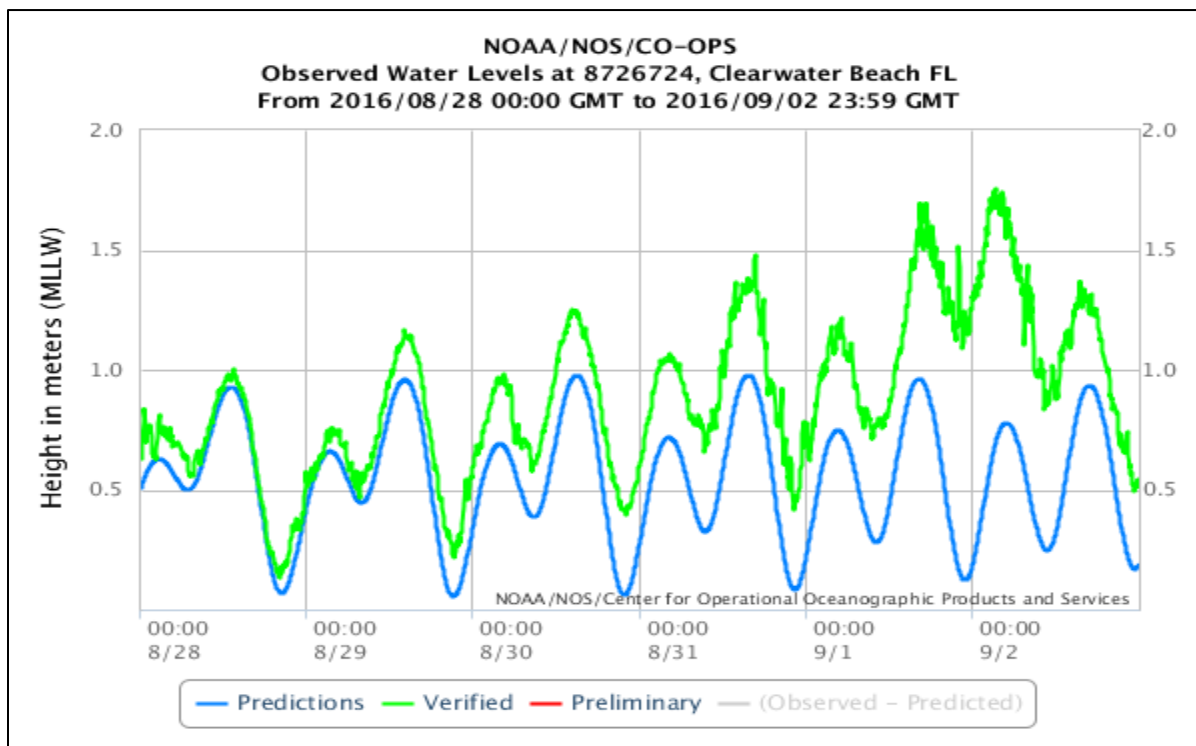


Figure 36. Wind speed pre-Hermine, July 28<sup>th</sup> – August 2<sup>nd</sup> , 2016.

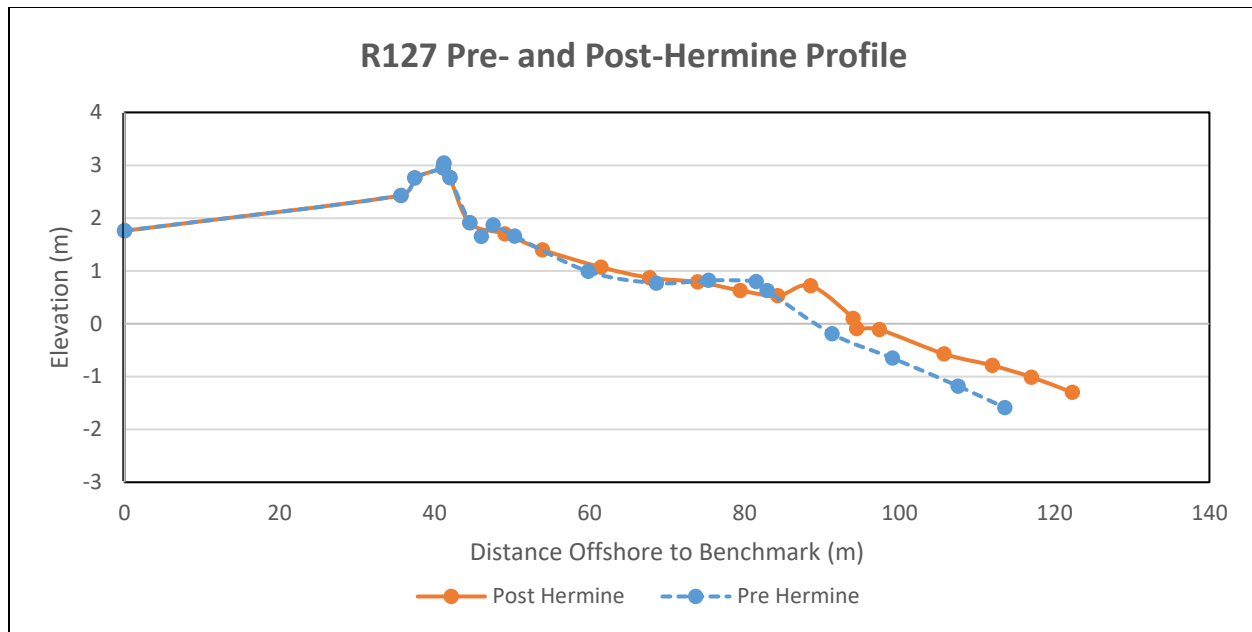




**Figure 38-1.** Water level pre-Hermine, July 28<sup>th</sup> to August 2<sup>nd</sup>, 2016 (NOAA).

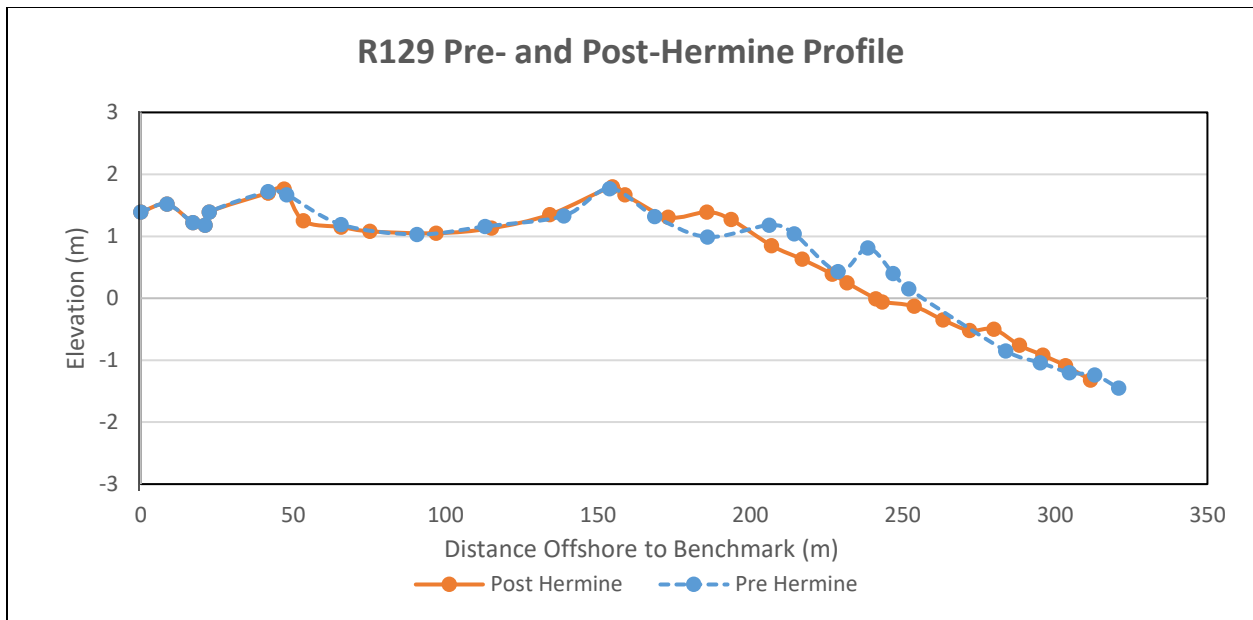


**Figure 38-2.** Water level during Hermine, August 28<sup>th</sup> to September 2<sup>nd</sup>, 2016 (NOAA).

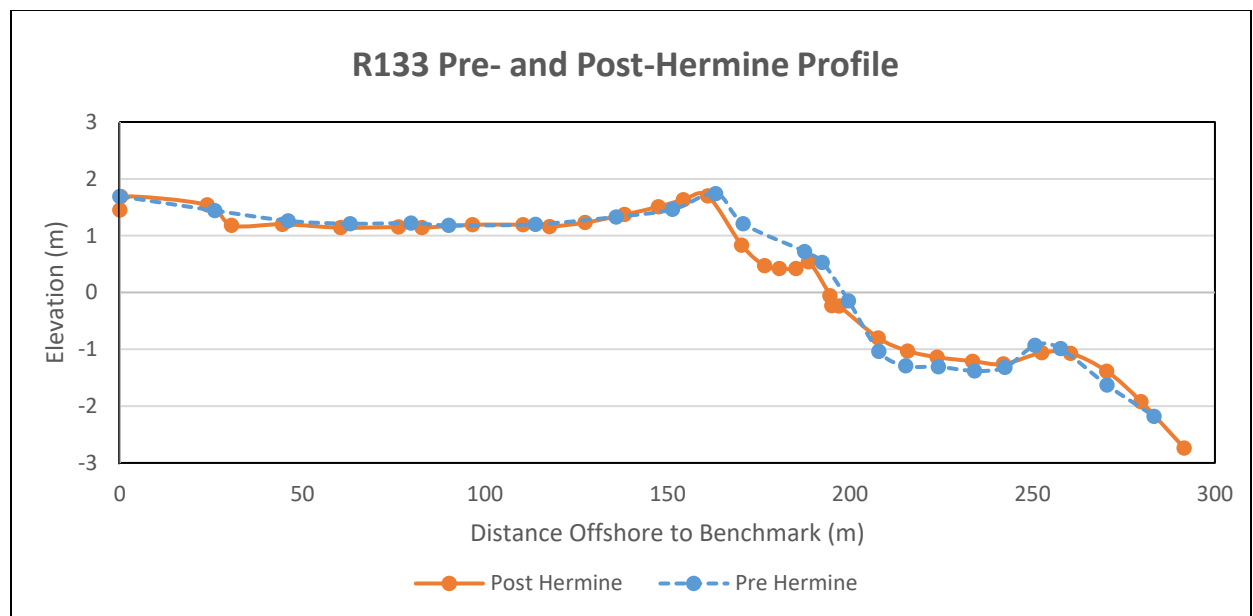


**Figure 39.** Beach profile change at survey line R127 due to Hermine.

Erosion occurred in the nearshore zone at profile R129 (Figure 40). The pre-storm berm crest at 210 m away from benchmark moved landward for 20 m forming a new storm berm. The pre-storm active berm crest at approximately 240 m away from benchmark was completely eroded away; the nearshore zone gained slight amount of sediment deposition and a subtle sand bar was developed at the location approximately 280 m away from benchmark (Figure 40). The profile change at survey line R133 was similar to the change at R129 (Figure 41). A storm berm was developed at the location approximately 180 m away from benchmark on the pre-storm dry beach; the nearshore zone gained sand; and pre-storm offshore sand bar moved seaward.



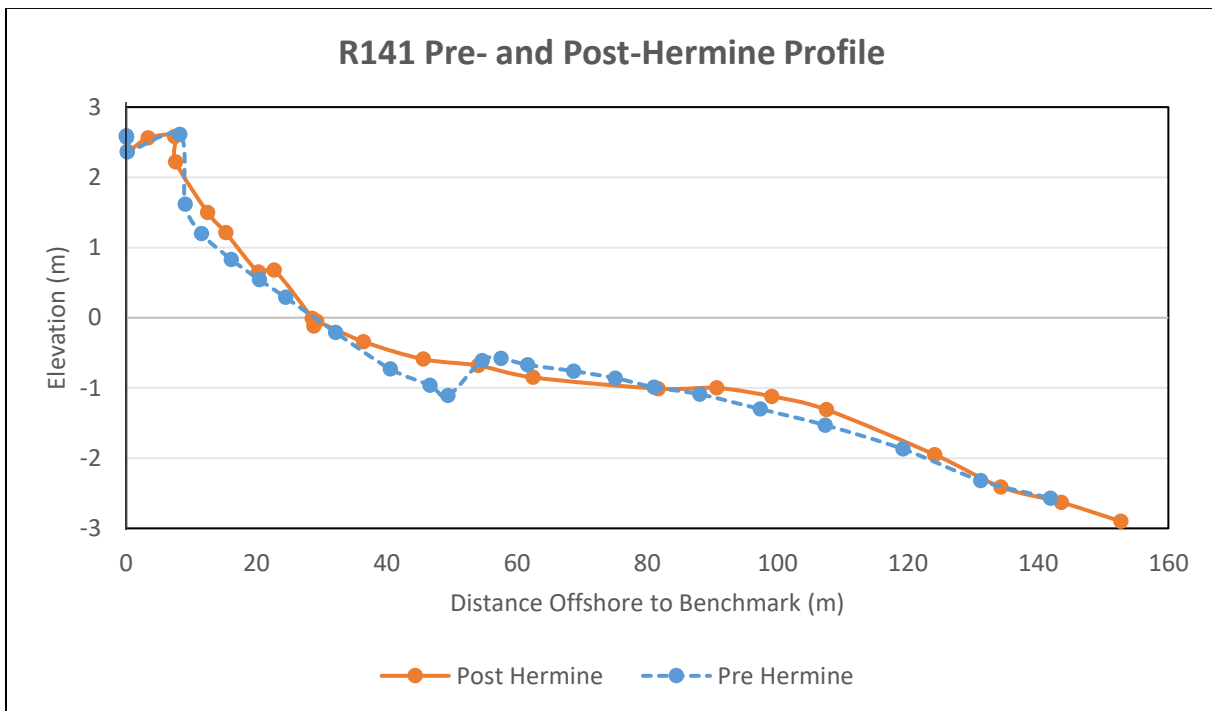
**Figure 40.** Beach profile changes at survey line R129 due to Hermine.



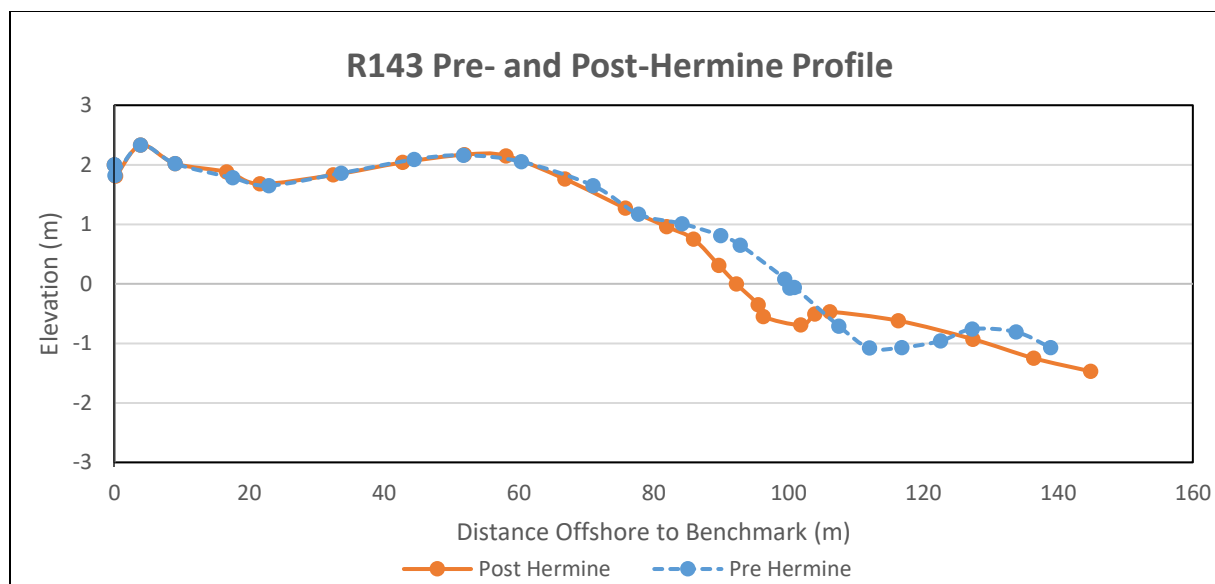
**Figure 41.** Beach profile changes at survey line R133 due to Hermine.

Survey lines R141 and R143 both gained sand on the dry beach (Figure 42 and Figure 43). At line R141, the nearshore zone also gained sediment. At an elevation of 1 m, the contour line moved seaward approximately 5 m. However at profile R143, the nearshore zone experienced erosion. At an elevation of 0 m, the contour line moved landward approximately 8 m. Meanwhile, a trough was developed at the location approximately 100 m away from benchmark and the sand bar moved landward for approximately 20 m.

Overall, Hermine caused nearshore erosion in the middle part of Treasure Island and at the southern end of Sunset Beach (R143). Meanwhile, beach accretion occurred at Sunshine Beach. The dry beach became wider at Sunshine Beach and the sand bar at R143 moved landward.



**Figure 42.** Beach profile changes at survey line R141 due to Hermine.



**Figure 43.** Beach profile changes at survey line R143 due to Hermine.

#### 4.5 Beach profile changes induced by winter storms in winter seasons.

Winter storms are generated by passages of cold fronts and can generate high waves. Consequent to the wave conditions, sediment transport in the study area tends to be episodic as it is controlled by high-energy events typically associated with the frequent passages of winter cold fronts (Walton, 1973; Davis1997; Elko et al., 2005; Elko and Wang, 2007). According to field measurements by Wang et al. (2007), the frequent passage of winter cold fronts and the associated high waves from the north are the key factors to beach morphodynamics of West-Central Florida.

##### 4.5.1 Beach profile changes induced by winter storms in winter of 2014

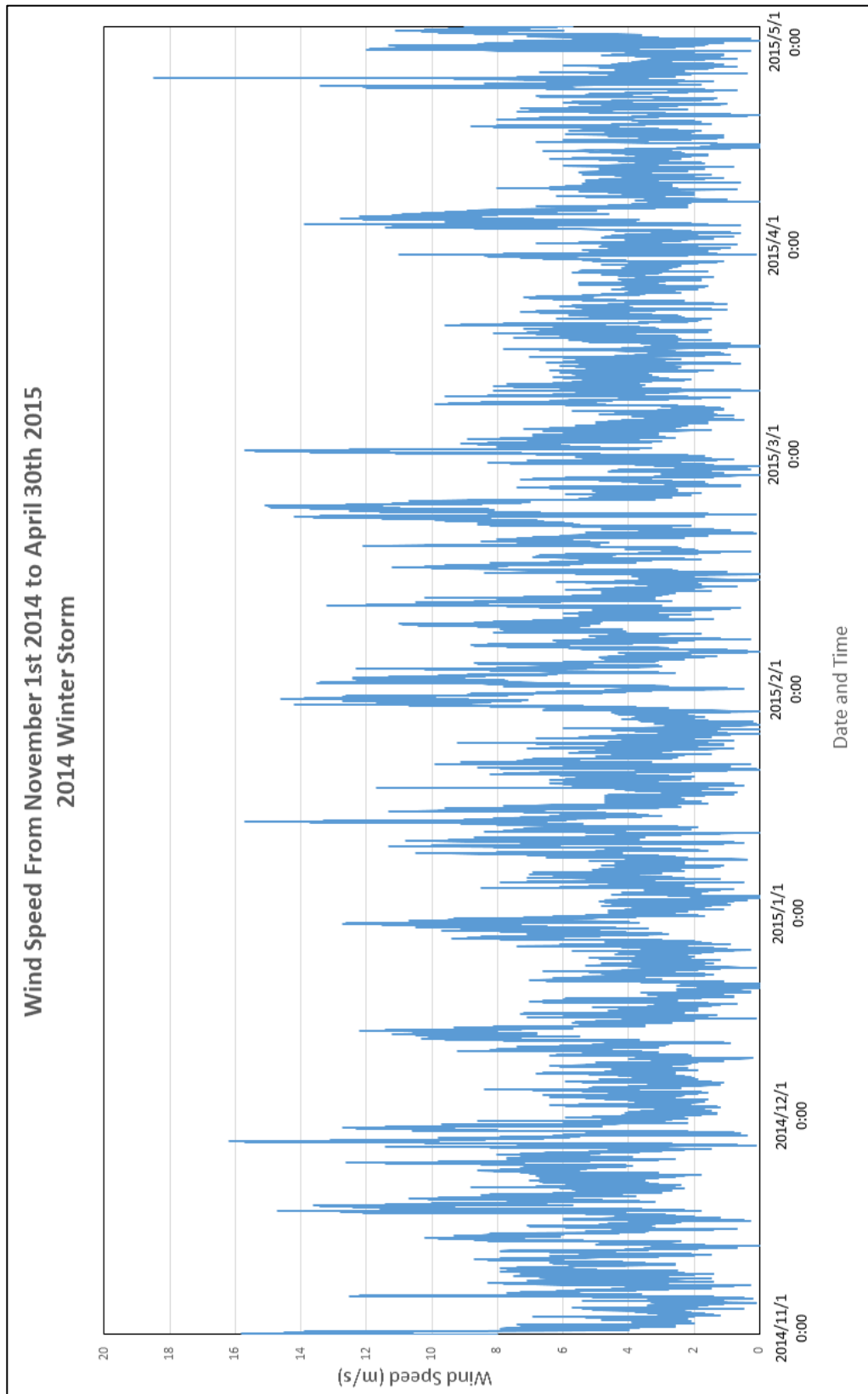
Winter storms can generate strong wind and high waves. The winter storms examined in this study did not generate significant storm surge. Therefore, storm surge is not discussed here as a significant factor. Furthermore, winter storms occur rather frequently, every 10 to 14 days (Wang et al., 2011). Instead of examining the impact of individual winter storm, the impacts of several winter storms during the winter season are discussed here. For the winter season of 2014,



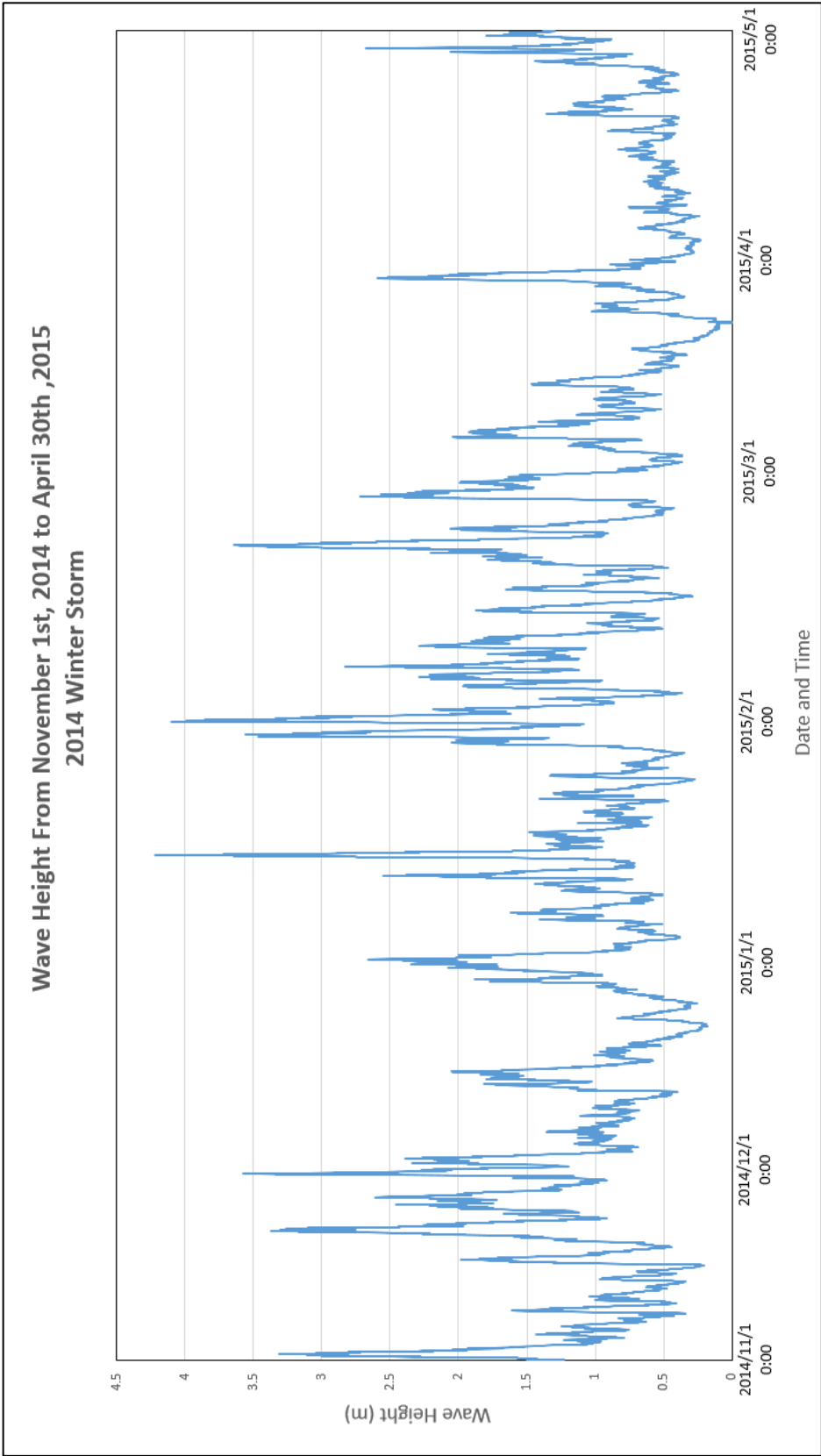
data on wind speed and wave height were downloaded from NOAA for the period time of November 1<sup>st</sup> 2014 to April 30<sup>th</sup> 2015 to cover the entire winter season. Pre-storm beach profile was measured on December 15<sup>th</sup> 2014 and post storm beach profile was measured on February 27<sup>th</sup> 2015.

Figure 44 illustrates the wind speed changes during the winter of 2014. Roughly at the beginning, middle and end of every month, wind speed increased to a high level of over 12 m/s. Wind speed of approximately 16 m/s occurred in November, January and February. Comparing to the wave height data in the same period time (Figure 45). When wind speeds reached approximately 15.8 m/s at the beginning of November 1<sup>st</sup> 2014, and wave height rose to a peak of 3.3 m. When wind speed reached 16.2 m/s around the end of November, wave height at the same time was nearly 3.6 m. Similarly, when wind speeds reached the peaks around the end of December, the middle of January, the beginning of February and end of February, wave heights rose to peak values at the same time.

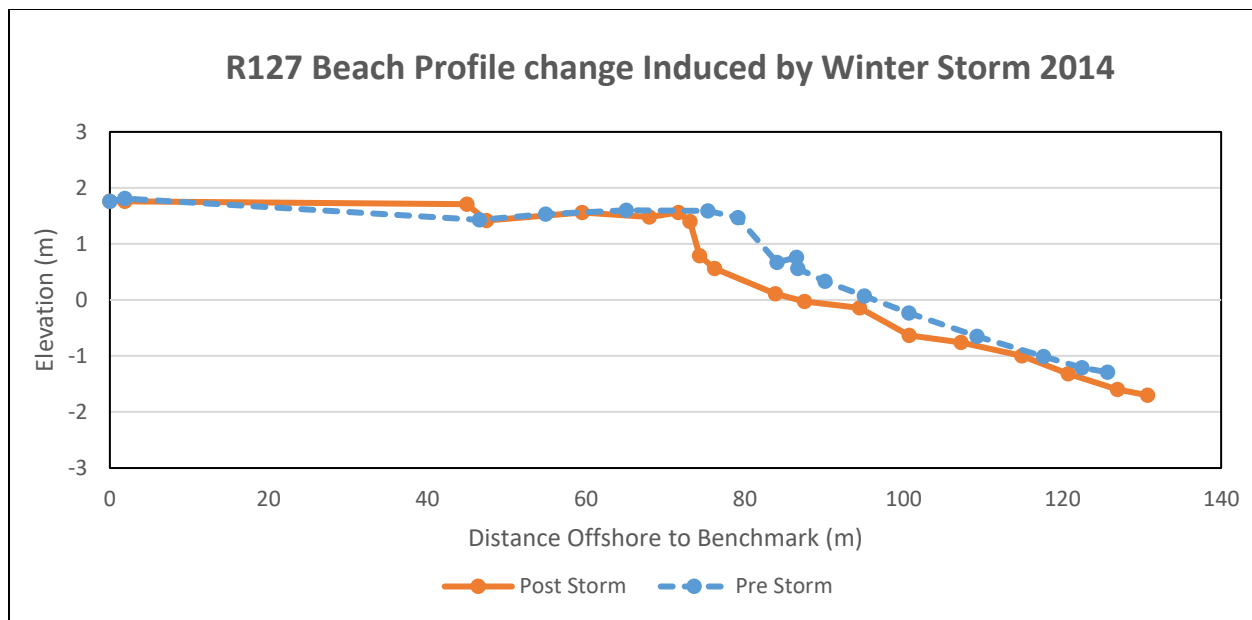
Survey line R127 suffered the most severe erosion along the Treasure Island coast during the 2014 winter season (Figure 46, see page 57). A beach scarp was formed on the dry beach approximately 75 m away from the benchmark. The dry beach was severely eroded, as well as the nearshore zone. At the elevation of 1.0 m, the contour line moved landward for approximately 8 m; at the elevation of 0.0 m, the shoreline was eroded approximately 12 m landward; and at the elevation of -1.0 m, the beach profile retreated approximately 2 m. As discussed previously, beach profile changes at survey line R127 are strongly affected by John's Pass ebb tidal delta. As compared to the beach accretion during tropical storm Hermine in 2016, winds of the winter storm came from the north which generated southward sediment transport. This southward longshore sediment transport resulted in the measured beach erosion.



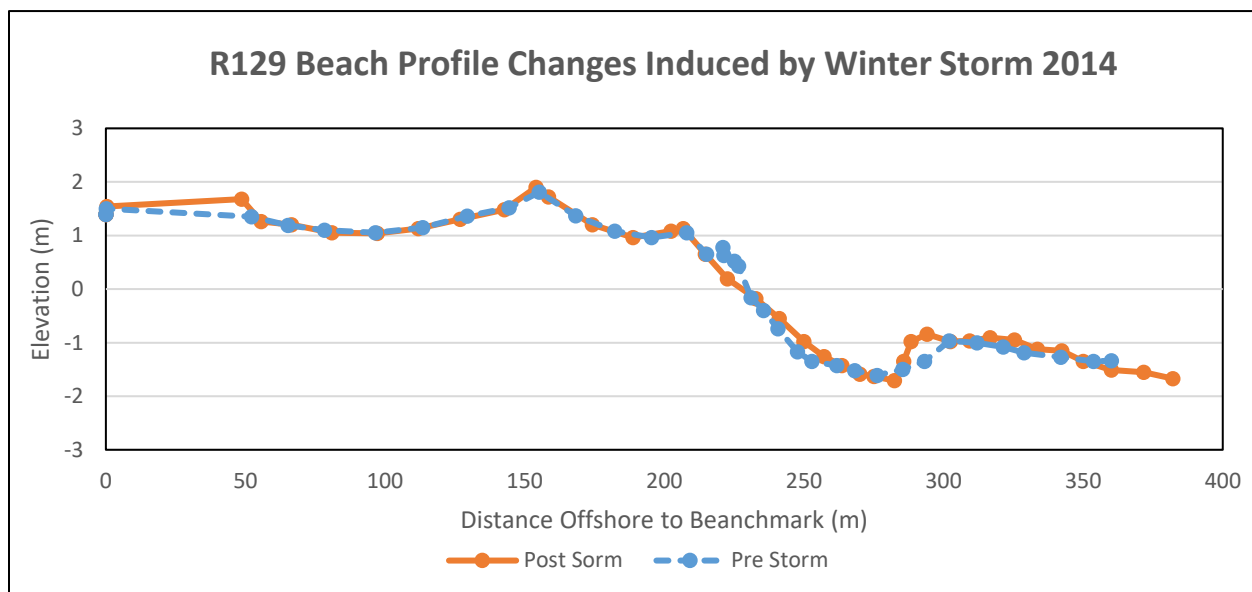
**Figure 44.** Wind speed during the winter of 2014, November 1<sup>st</sup> 2014 to April 30<sup>th</sup> 2015.



**Figure 45.** Wave height changes during the winter of 2014, November 1<sup>st</sup> 2014 to April 30<sup>th</sup> 2015.



**Figure 46.** Beach profile changes at survey line R127 due to winter storm 2014.



**Figure 47.** Beach profile change at survey line R129 due to winter storm 2014.

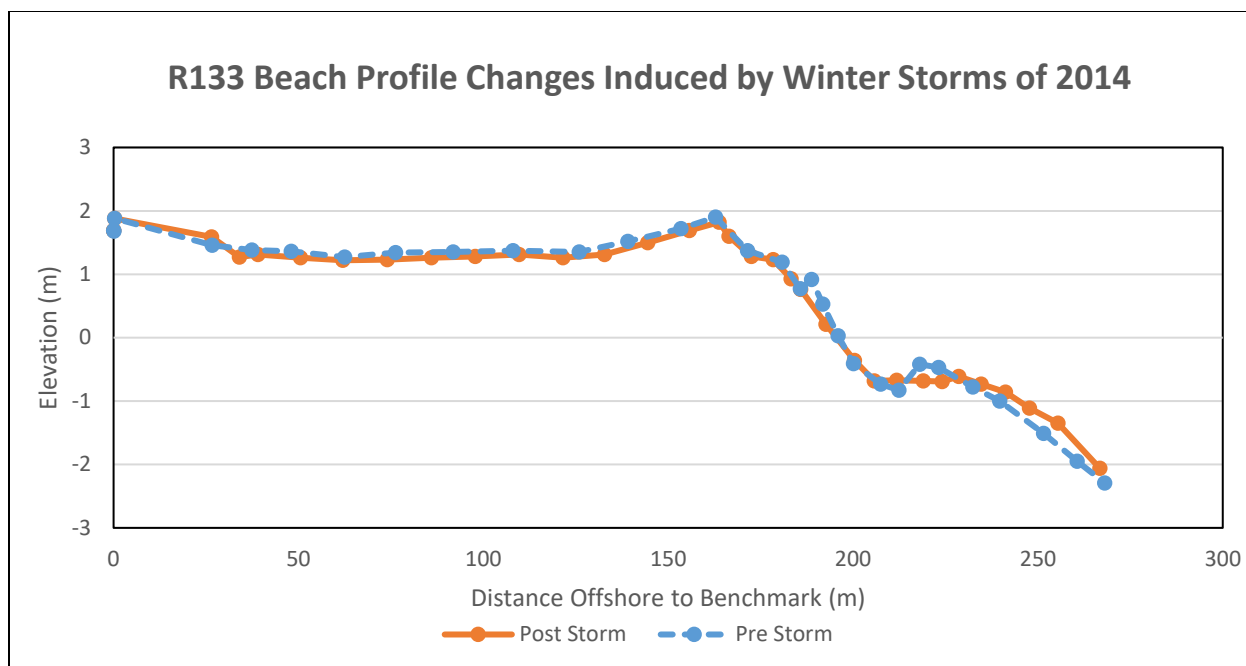
Compared to R127, survey line R129 did not lose as much sand (Figure 47). The dry beach still suffered some erosion and the berm crest at approximately 225 m away from benchmark was eroded away. The nearshore zone gained a small amount of sediment. The sand

bar offshore at approximately 300 m from the benchmark migrated approximately 10 m landward. At the elevation of 1.0 m, the dry beach profile almost remained its characteristics; at the elevation of 0.0 m, the profile did not change, but the gradient of the nearshore area became gentler; and at the elevation of -1.0 m, the sand bar moved 10 m landward.

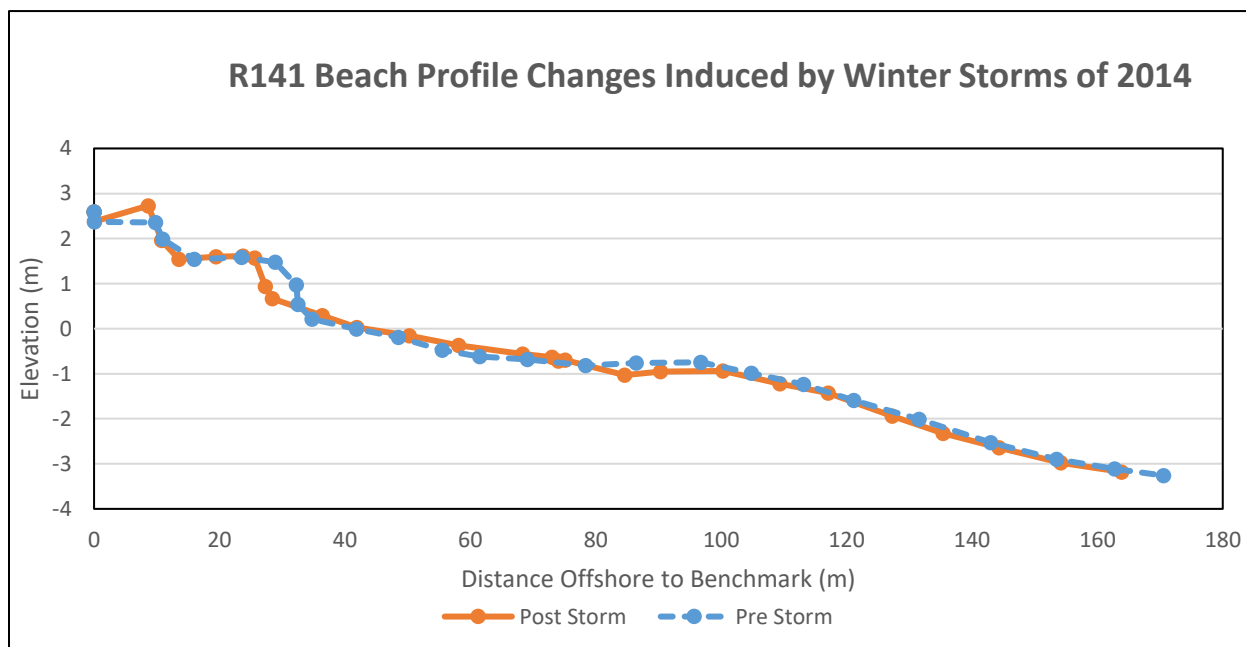
In the Middle Beach of Treasure Island, beach-profile changes were similar to R129. At profile R133, the dry beach experienced minor erosion (Figure 48). The berm crest at approximately 180 m from the benchmark was eroded away. The sand bar at approximately 220 m from the benchmark at the elevation of -0.5 m was moved seaward to approximately 250 m from benchmark. At the elevation of 1.0 m, the contour line moved landward for less than 1 m; at the elevation of 0.0 m, the coastline did not change but the slope became gentler; and at the elevation of -1.0 m, the profile moved seaward for approximately 2 m.

Survey line R141 experienced dry beach erosion (Figure 49). The dune line at R141 moved landward for 2 m, with a dune scarp developed at 30 m from the benchmark. The nearshore zone was slightly eroded and the offshore zone did not change much. Profile R143 experienced slight erosion on the dry beach. The nearshore zone experienced more severe erosion (Figure 50).

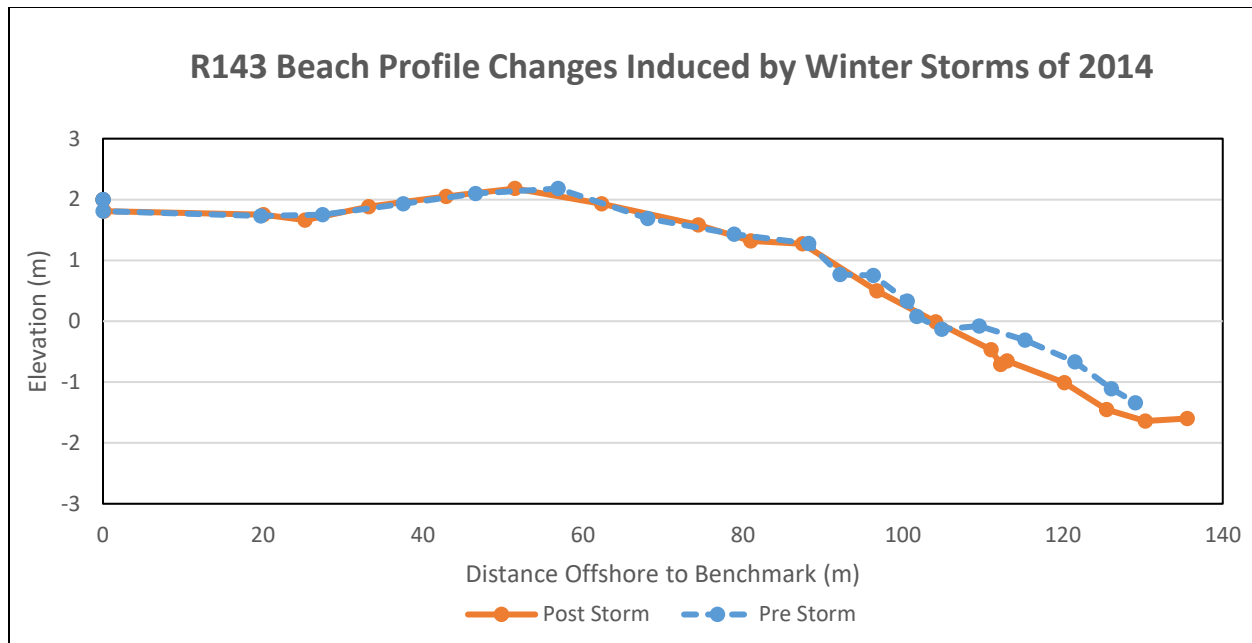
Overall, the coastline of Treasure Island experienced erosion in varying degrees during the winter season of 2014. The northern part of the island experienced more erosion than the middle and southern part, driven by the southward longshore sediment transport.



**Figure 48.** Beach profile changes at survey line R133 due to winter storms of 2014.



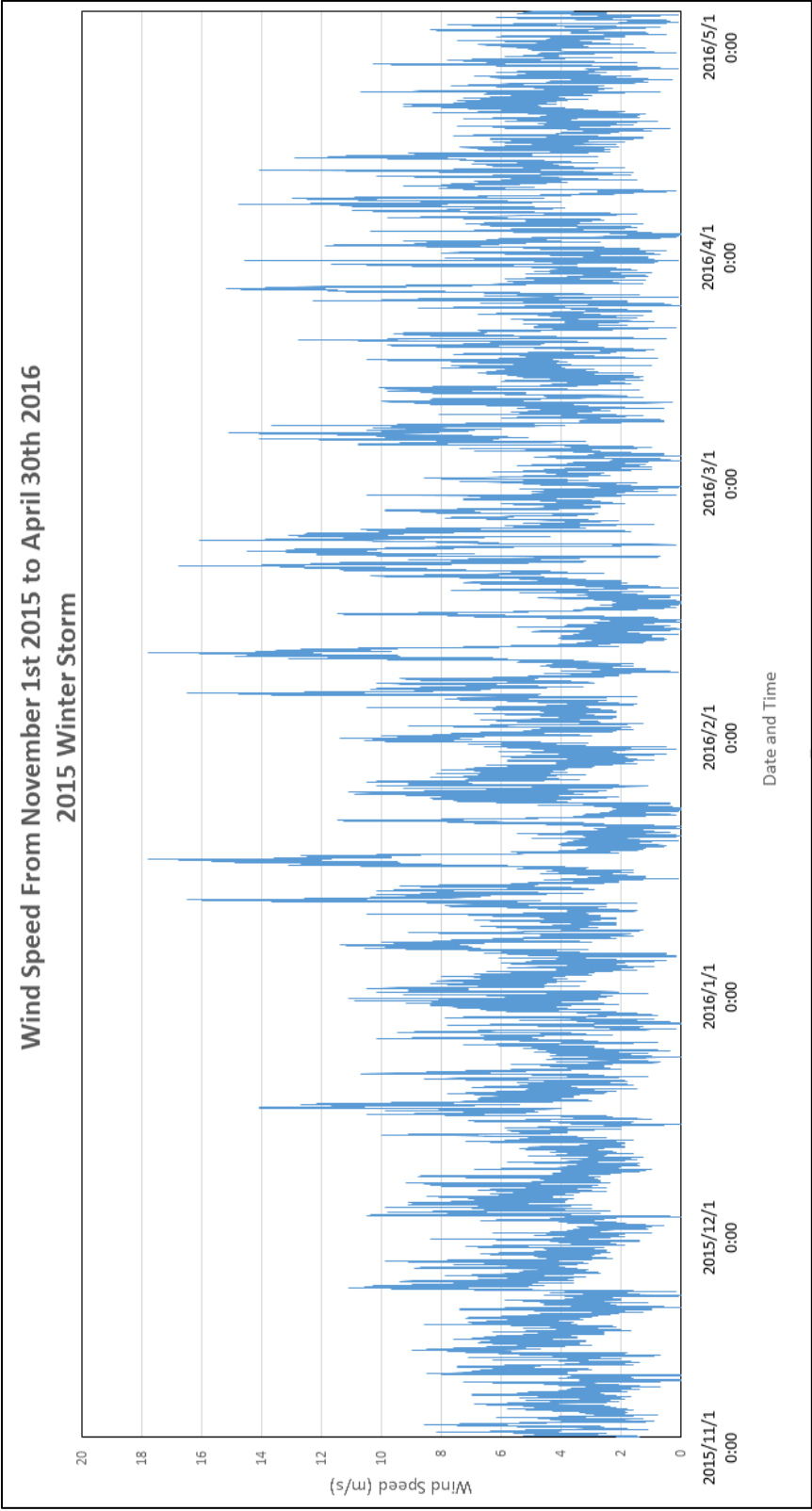
**Figure 49.** Beach profile changes at survey line R141 due to winter storms of 2014.



**Figure 50.** Beach profile changes at survey line R143 due to winter storms of 2014.

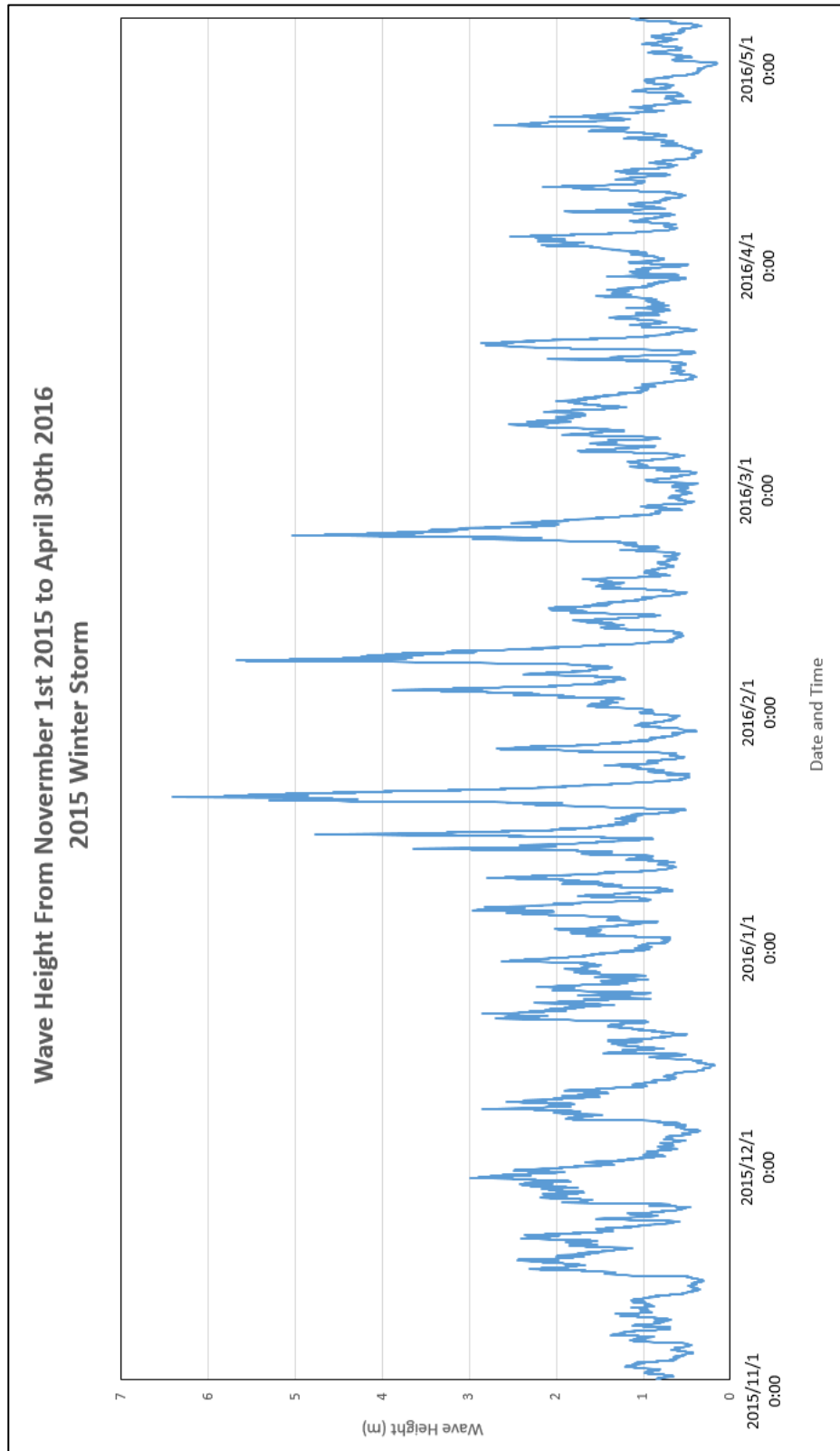
#### 4.5.2 Beach profile changes induced by winter storms in the winter of 2015

In the winter 2015, wind conditions were wilder than the winter of 2014 (Figure 51). Most of the time, wind speeds remained below 12 m/s. Only during a couple of days wind speeds reached more than 14 m/s. However, waves generated by the wind were higher than the waves in winter 2014 (Figure 52). Wave heights during this period of time remained mostly below 3 m. In comparison, wave height in year 2016 reached 4.77 m and 6.41 m respectively. In early and late February 2016, wave height achieved 5.68 m and 5.04 m respectively as another two peaks as shown in Figure 52. Meanwhile, at these times wind speeds also increased to the highest values of 17.9 m/s and 16.8 m/s as shown in Figure 51. The peak wave height during the winter was 6.41 m and the mean wave height was 1.26 m.



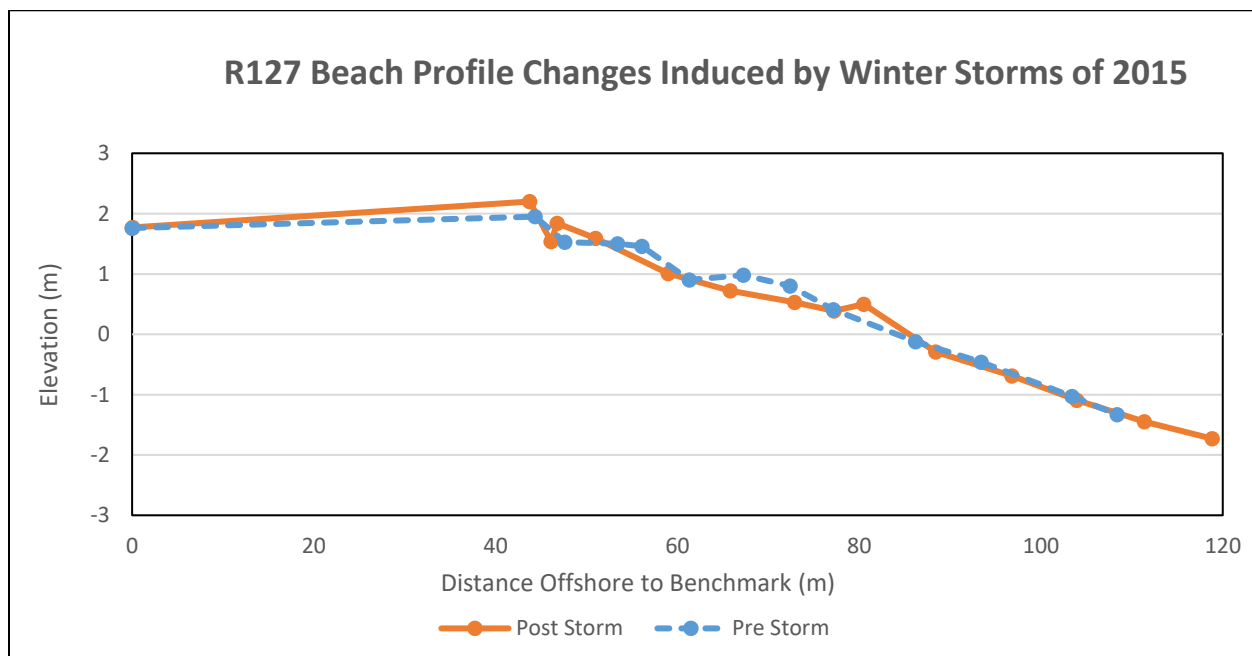
**Figure 51.** Wind speed changes during the winter of 2015, November 1<sup>st</sup> 2015 to April 30<sup>th</sup> 2016.



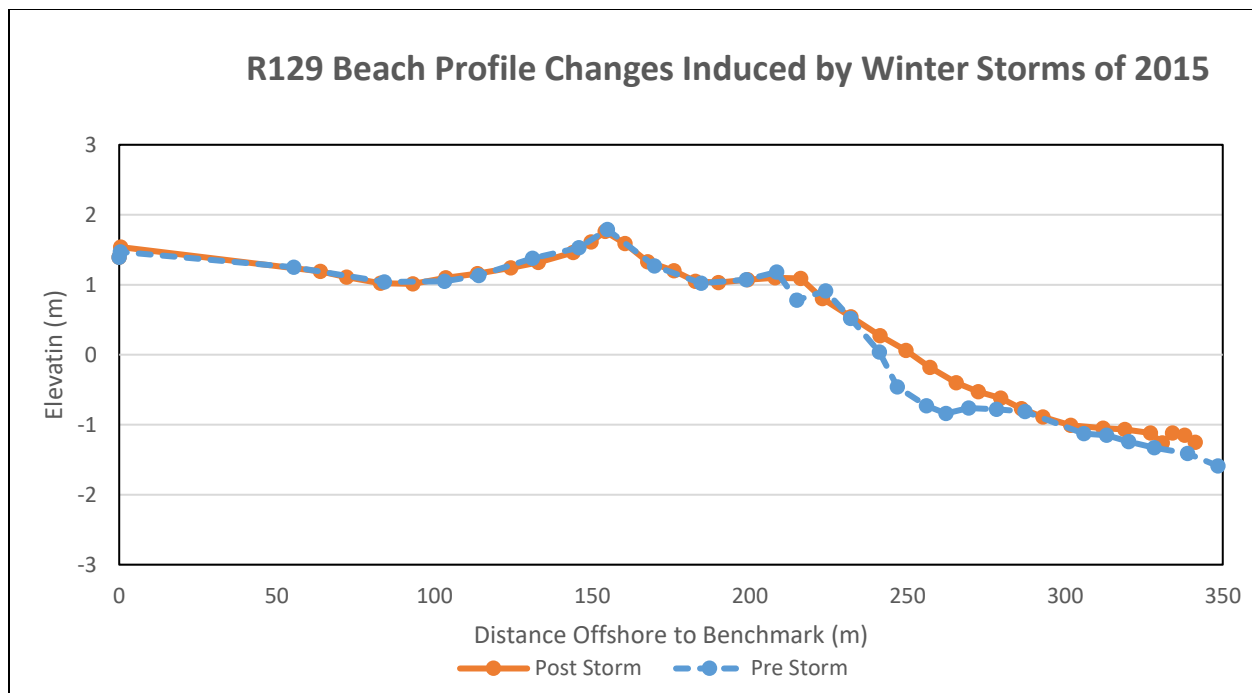


**Figure 52.** Wave height changes during the winter of 2015, November 1<sup>st</sup> 2015 to April 30<sup>th</sup> 2016.

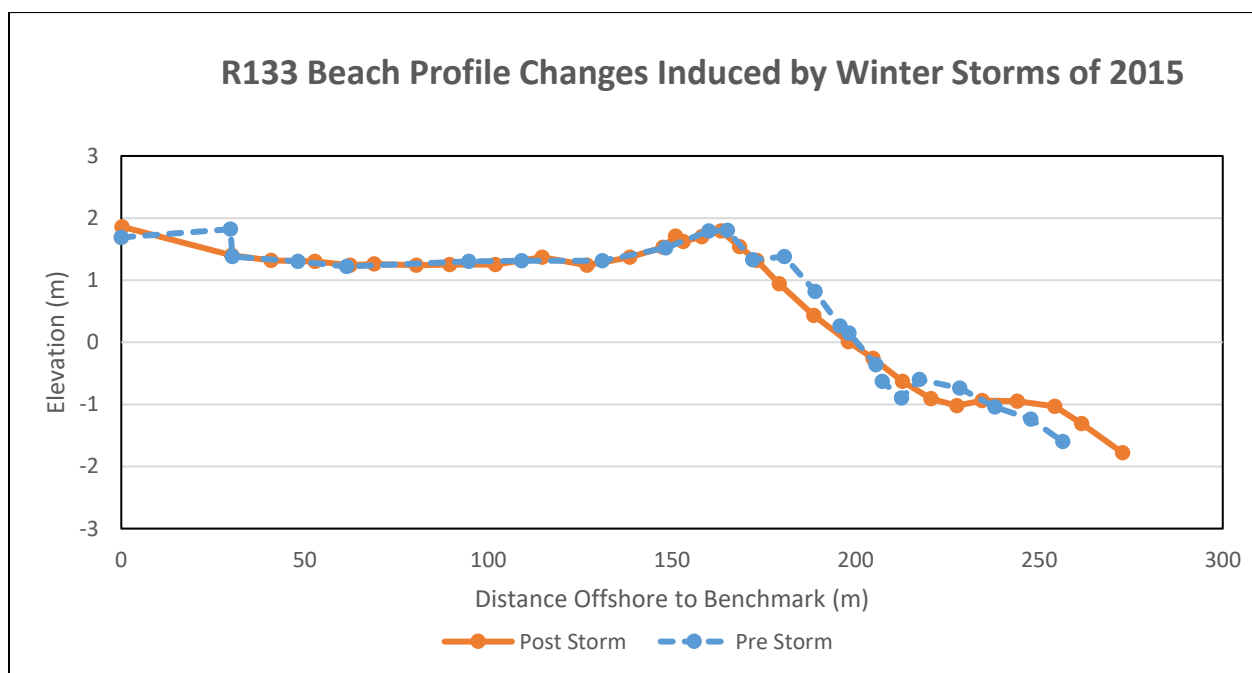
Induced by winter storms of 2015, Treasure Island was eroded in varying degrees along the entire island. Pre- and post-storm beach profiles were measured on December 14<sup>th</sup> 2015 and March 4<sup>th</sup> 2016, respectively. The dry beach at survey line R127 gained a small amount of sand (Figure 53). The dry beach at R129 did not change much, while the nearshore zone gained sediment from 240 to 280 m away from benchmark, likely due to the sand bypassing at the attachment point (Figure 54). Sediment deposited in the offshore zone was also measured. In the middle of the island, the beach was mostly stable with modest erosion that occurred on the dry beach and in the nearshore zone (Figure 55). The sand bar at approximately 220 m from benchmark migrated offshore. Sunset Beach experienced modest erosion in the nearshore zone and some deposition further offshore (Figure 56 and Figure 57).



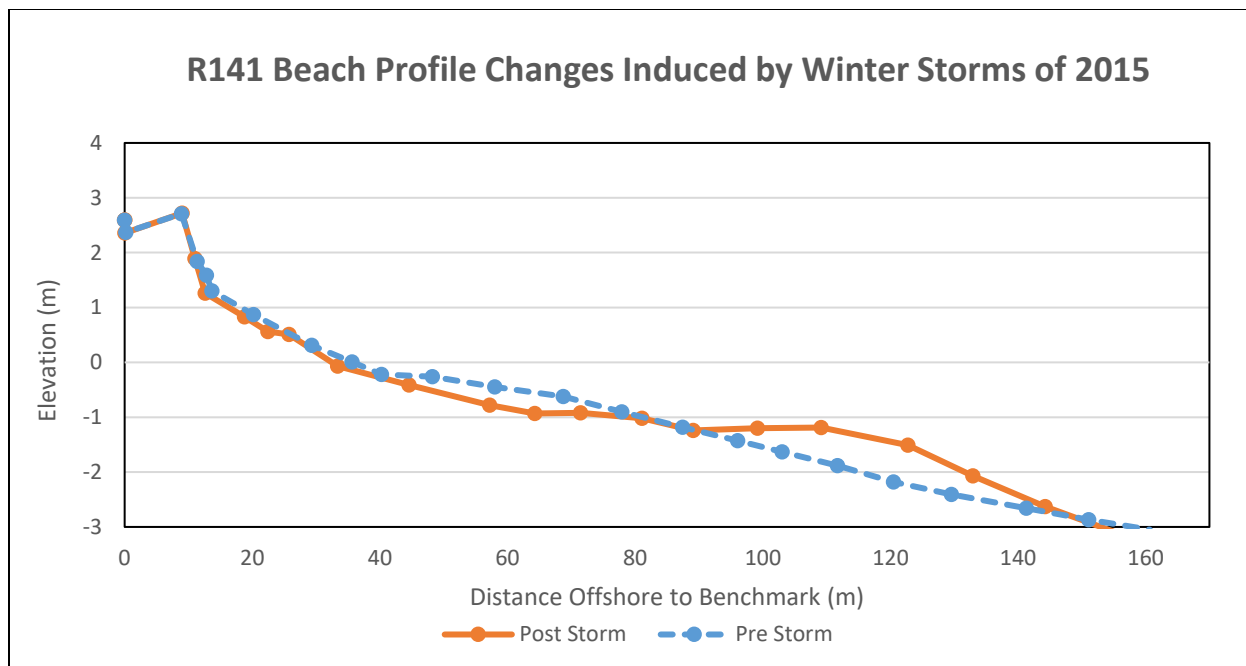
**Figure 53.** Beach profile changes at survey line R127 due to winter storms of 2015.



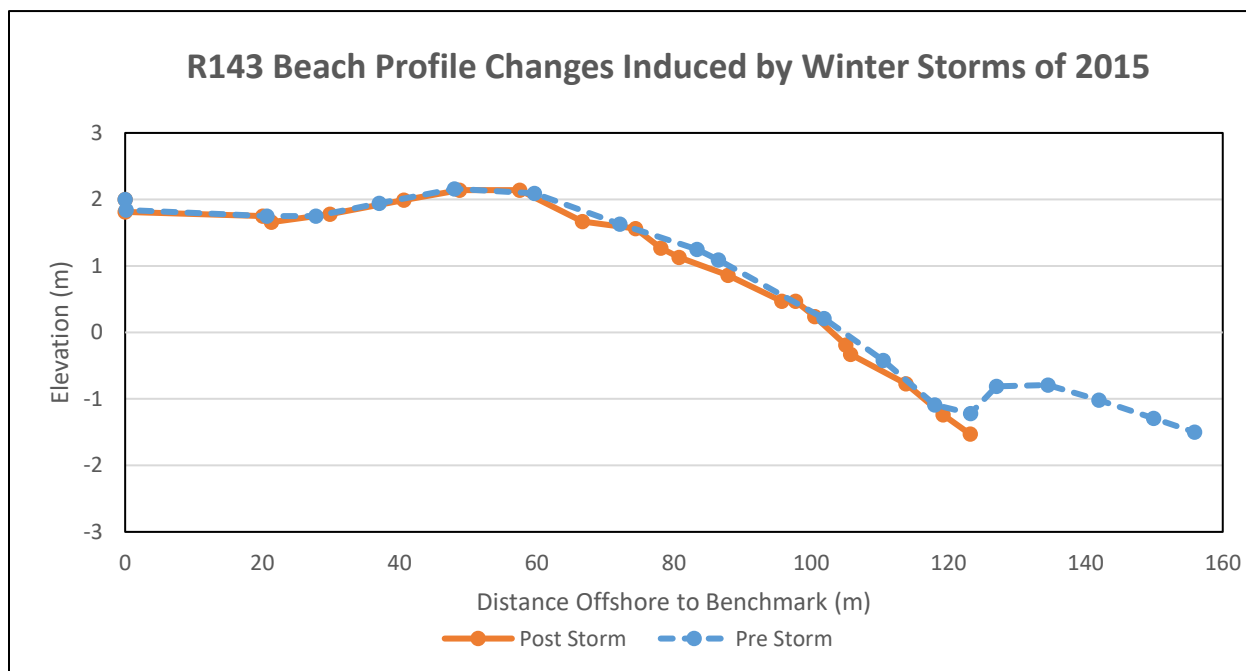
**Figure 54.** Beach profile changes at survey line R129 due to winter storms of 2015.



**Figure 55.** Beach profile changes at survey line R133 due to winter storms of 2015.



**Figure 56.** Beach profile changes at survey line R141 due to winter storms of 2015.



**Figure 57.** Beach profile changes at survey line R143 due to winter storms of 2015.

#### 4.6 Summary

In order to investigate the effect of storms on beach erosion, the condition of the each storm in this study is illustrated in Table 2. Tropical storm Alberto generated higher storm surge and stronger winds than tropical storm Fay. The mean water level during Alberto and Fay were similar. As discussed in the previous section, slight erosion occurred at the study area during tropical storm Fay. However, severe erosion occurred at Sunshine Beach during tropical storm Alberto. The reason is probably that Alberto happened just after the beach nourish project in 2006. The beach profile was in still the same as the post-nourishment adjustment. This caused more severe beach erosion by Alberto as compared to tropical storm Fay.

**Table 2.** Summary of data collected during each storm.

	Alberto (2006)	Fay (2008)		Debby (2012)	Hermine (2016)	Winter (2014)	Winter (2015)
Duration (days)	5	12		6	6	241	241
Distance (km) <sup>(1)</sup>	275 (N) <sup>(2)</sup>	260 (S) <sup>(2)</sup>	230 (N)	170 (N)	290 (N)	---	---
Peak storm surge (m)	0.73	0.26		0.95	1.35	---	---
Peak wind speed (m/s)	20.5	15.4		19.6	21.1	18.5	17.8
Mean water level (m)	0.64	0.56		1.02	0.89	---	---
Peak wave height (m)	---	2.37		5.58	7.30	4.22	6.41
Mean wave height (m)	---	1.08		2.56	2.25	1.03	1.26

<sup>(1)</sup> Distance refers to the distance from landfall area to study area.

<sup>(2)</sup> N: the landfall area is to the north of study area; S: the landfall area is to the south of study area.

Tropical storms Debby and Hermine generated similar wave conditions and wind strength. The peak wind speeds were 19.6 m/s and 21.1 m/s during Debby and Hermine, respectively. The peak wave height were 5.58 m and 7.30 m during Debby and Hermine, respectively. Although peak wave height during Hermine is higher than that during Debby, the mean wave height was similar (2.25 m during Hermine and 2.56 m during Debby). On the other hand, Debby made its landfall much closer than Hermine did. Meanwhile the mean water level during Debby was 1.02 m, which was higher than the mean water level during Hermine (0.89 m). This is likely the reason that the entire Treasure Island coast suffered nearshore erosion during Debby. However, beach accretion occurred at survey R127 during Hermine. Therefore, water level became a significant factor that could cause nearshore erosion while other factors were close. Storms in winter seasons of 2014 and 2015 did not cause significant erosion along Treasure Island coastline. Compared to tropical storm Fay, mean wave height and wind strength were similar. On the other hand, high storm surge are not typically generated during winter seasons. Therefore, winter seasons can barely change beach morphology.

## **CHAPTER 5: CONCLUSIONS**

Sandy beaches are one of the most dynamic coastal environments. Tropical storms and winter storms can cause substantial beach changes. In this study, beach morphology is subjected to more erosion during short-term tropical storms than during long-term winter storms. Tropical storms could substantially increase wind speeds, wave heights and induce storm surge in a short period of time. The stronger the offshore wind conditions, generate higher incident waves, therefore, beach profiles tend to be subjected to more erosion. However, storms during winter seasons typically do not generate large storm surge. Wind speeds are slower and wave heights are lower than those measured during short-term tropical storms. Therefore, no significant beach morphology changes occur during winter seasons.

It is also indicated in this study that when wave conditions and wind strength are similar (e.g. tropical storm Debby and Hermine), mean water level and distance from landfall become dominant factors. The tropical storm with a closer landfall to the study area can cause more severe erosion than those with a landfall location further away. A higher storm surge coincides with high tide and high wave as the dominant mechanisms that cause beach erosion. Additionally, beach nourishment may be an effective method to compensate beach erosion as morphology at Sunset Beach did not suffer severe erosion as did Sunshine Beach during tropical storm Alberto. Meanwhile, John's Pass ebb tidal shoal played an important role in Treasure Island's beach morphology change. The ebb tidal delta blocks the sediment transport along barrier islands. Therefore, a comprehensive investigation of storm induced beach profile changes aids our understanding in beach morphodynamic processes.

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